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# ON THE INNERVATION OF THE NODAL TISSUE OF THE MAMMALIAN HEART.

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SINCE their discovery, the sino-auricular (Keith-Flack, 1907) node and the auriculo-ventricular bundle (Kent and His, 1892) have been extensively described by many writers.

Histological research has, until recently, concerned itself chiefly with the nature and distribution of the primitive muscle, which is the most noticeable feature of those structures.

In 1906, Tawara (1), whose description of the muscular element of the auriculo-ventricular node and bundle is most exhaustive, stated that nerve fibres accompany the bundle in the sheep. In the bundle of the sheep and calf the nervous tissue is very abundant, and cells and large strands of nerve fibres form a striking feature in sections stained by Van Gieson's method, but Wilson (2) was the first (1909) to make a study of the nervous element of the bundle by special nerve stains. He used the intra-vitam methylene blue method, and worked chiefly with the calf, sheep, and pig. He states that he was less successful with human hearts and with those of carnivora. He describes in the calf's heart numerous nerve cells and ganglia, large nerve strands, and a very rich plexus of exceedingly fine fibrils, breaking up and closely surrounding the muscle fibres and groups of muscle fibres, but without any definite end organs in relation to the muscle cells.

Lydia de Witt (3) stated that in the calf and sheep nerve cells and fibres were numerous, and that the fibres could be followed to the finer ramifications of the bundle. She does not give a detailed description of the nerve element: her paper deals chiefly with the course and final distribution of the bundle.

Morison (4) has studied the nervous element of the sino-auricular node and the auriculo-ventricular bundle with the object of determining "whether the muscle cells of the sino-auricular and auriculo-ventricular muscle were innervated, and, if so, the character and manner of such innervation." He examined the sheep and pig, but adds a note to the effect that he has found what he takes to be "ultimate innervation of the bundle" in man. He employed the method of Sihler, and describes the innervation of the sino-auricular muscle by moniliform threads applying themselves to the muscle cells. The Purkinje fibres of the auriculo-ventricular bundle, he states, are supplied by shorter fibrils coming from the surrounding plexus, or by longer ones which he was able to trace to their origin from larger nerves.

B. S. and A. Oppenheimer (5) have stained nerve fibres and cells in the sino-auricular node of the sheep by the methylene blue intra-vitam method. They describe a few cells and fine nerve filaments forming a plexus round the muscle fibres. They, like Wilson, were unable to find any definite end organs. The plexus is a very fine one, and enters into very close relation with the muscle fibres. Their findings for the sino-auricular node are very similar to Wilson's for the auriculo-ventricular bundle as regards the finer nerve elements: they differ in that nerve cells are rarely found in the sino-auricular node.

It is noteworthy that, with the exception of Morison's, all the work done on the innervation of the primitive muscle has been done by means of methylene blue, and it appeared likely that, while the larger nerve strands found in the calf and sheep are absent in most other mammals, the failure to discover fine nerve elements in the hearts of man and of carnivora might be due to failure of the stain. Other classes of mammals have not been examined with regard to the innervation of the nodal tissue.

I have therefore attempted to determine the innervation of the primitive muscular tissue by means of different stains and in a number of different mammals.

The animals used for this research have been, chiefly, the monkey, guinea-pig, and rat. I at first investigated the innervation of the bundle in the hearts of calves and sheep by means of Cajal's silver method. As my results were mainly corroborative of those of Wilson (2), I shall not describe them here. I have also used human hearts and those of cats.

## Methods.

The methods employed were Cajal's silver-reduction method (6) and the methylene blue intra-vitam method as described by Wilson (7). I have used the Van Gieson method as a control, although the Cajal method stains muscle quite sufficiently well to enable an exact location of the primitive

muscle to be made, and the methylene blue sections were counterstained with safranine for this purpose.

I employed the method of Cajal with previous fixation in ammoniacal alcohol (6). The method is as follows:—

(1) Fixation in:

| | |
|---|---|
| Alcohol, 96 per cent. | 100 c.c. |
| Ammonia | 10 drops. |

24 hours.

(The specimens are best immersed first in weaker alcohol, with the same proportion of ammonia, a few hours.)

Wash in distilled water.

(2) Impregnation with silver nitrate:

1·5 per cent. at temp. 36° C.

6 to 8 days.

Wash in distilled water.

(3) Reduction in:

| | |
|---|---|
| Ac. pyrogallic. | 1 grm. |
| Formol | 5 c.c. |
| Aq. dest. | 100 c.c. |

24 hours.

Wash in distilled water, pass through spirit, etc., imbed in paraffin in the usual way.

Sections were cut serially and in most cases about 8 $\mu$ thick. One section in five was usually mounted, although, in some cases, as in some of the monkey hearts, all the sections were mounted.

Some of the sections were toned in the following bath, freshly prepared,

| | |
|---|---|
| Ammon. sulphocyanide | 3 grms. |
| Sod. hyposulphite | 3 grms. |
| Dist. water | 100 c.c. |
| 1 per cent. gold chloride | a few drops, |

until the yellow colour had almost disappeared. They were then counterstained with safranine, which takes well after toning. It was found that only specimens in which the muscular and connective tissues had taken the impregnation very feebly, toned well. In others, toning resulted merely in a blackening of all structures. Where successful it gave much clearer and more beautiful results.

For the methylene blue method I followed closely Wilson's description (7), which is very complete. I used a very weak solution of the stain, and injected it through the aorta into the coronary arteries. Sections were cut in paraffin, serially, and about 10 $\mu$ thick. They were counterstained with safranine.

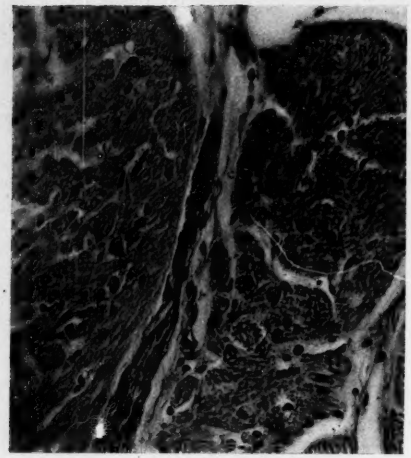

FIG. 1.—Sino-auricular node, monkey. Nerve passing through the node. (Silver, Leitz oc. 1, obj. 6.)

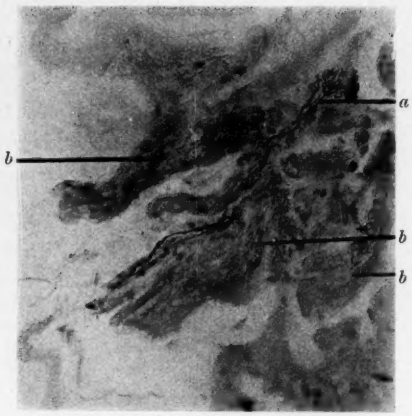


FIG. 2.—S.-A. node, monkey. Nerve fibres in the node. A small fibre is breaking up at (*a*) into numerous branches, (*b*) nodal muscle. (Silver, L. oc. 1, obj. 6.)

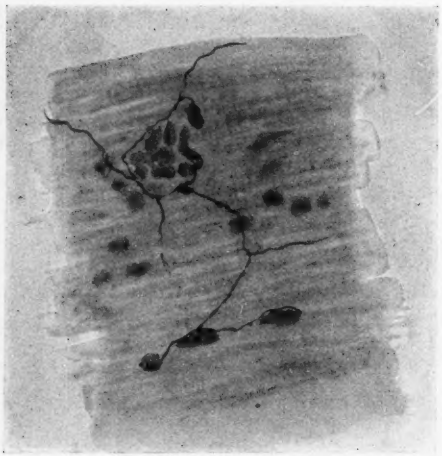

FIG. 3.—Part of fine plexus in S.-A. node, monkey. (Silver, L. oc. 4, obj. 6.)

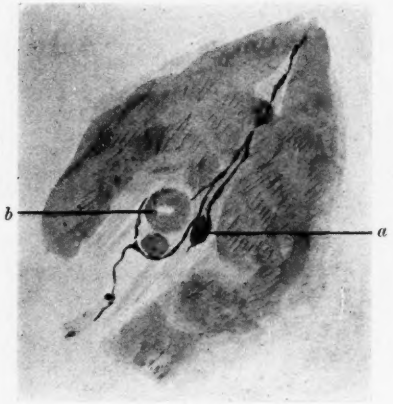


FIG. 4.—Small nerve fibril in S.-A. node (monkey) surrounding a nucleus at (*a*) and a muscle cell at (*b*). (Silver, L. oc. 4, obj. $\frac{1}{12}$.)

## The Nerves of the Sino-Auricular Node.

I have examined the nerves of the sino-auricular node only in the monkey and in man.

In the monkey (Callitrix) I have been able to show by Cajal's method a very extensive innervation of the muscle. Two or three relatively large nerves enter the node from the large ganglia immediately above it. Of these nerves, one (fig. 1) appears to pass through the node without branching and to be distributed in the auricular muscle. The others, which are of about the same size, break up early and give off probably all the small fibrils to supply the primitive (or nodal) muscle. These small fibrils sometimes form a very delicate plexus around groups of muscle fibres (fig. 3), and at other times a fibre breaks up into a brush of fibrils which ramify among the muscle cells (fig. 2). A great variety of endings was found: occasionally a single filament passes off from a larger fibre and applies itself to a muscle cell (fig. 4): frequently a single fibre or several fibres break up around one or several nuclei and form a fine network. These endings vary from intricate "corpuscles" (the largest of which run through 4–5 sections 7 $\mu$ thick) surrounding a number of nuclei, to a single fibril branching to enclose a single nucleus. There are frequently small varicosities on the course of these fibrils and at their terminations. A number of endings are shown at figs. 5 to 12 (pp. 6, 7).

The nuclei forming the centre round which these fibrils break up present several points of interest. In many cases they are obviously muscle nuclei contained in the delicately reticular muscle characteristic of the primitive tissue, showing the ordinary appearances of a muscle cell nucleus in this situation (figs. 7, 8, 12, pp. 6, 7) Sometimes there is a single nucleus with a relatively small amount of muscle substance surrounding it, and with a small tail of muscle. The cells at (*a*) and (*b*) in fig. 5, and at (*b*) in fig. 8 appear to be of this character. Some of the more complex endings surround a cluster of nuclei which appear to be muscle nuclei, but which are much more closely grouped than the nuclei of the surrounding muscle. This is the case with the ending shown at fig. 11, p. 7. One occasionally finds, associated with a terminal network, a group of nuclei of a character difficult to determine. Such a group is shown at fig. 9, p. 7. A terminal branching filament is here wound spirally round a number of nuclei lying between two strands of muscle. These nuclei are rather smaller than the average of the muscle nuclei, and do not appear to be surrounded by muscle substance.

Very closely resembling some of the more complex endings described above, are the networks occurring in the course of some of the fibres. A

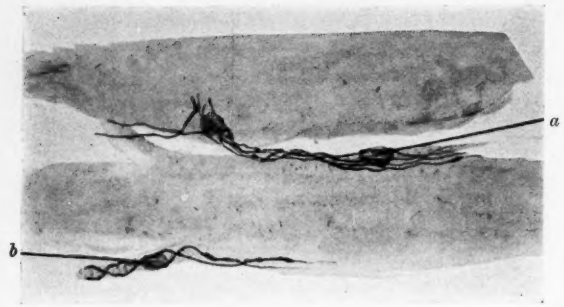


FIG. 5.—S.-A. node, monkey. Nerve fibrils surrounding nuclei. The nuclei at (*a*) and (*b*) have a small "tail" of muscle. (Silver, L. oc. 4, obj. $\frac{1}{12}$.)

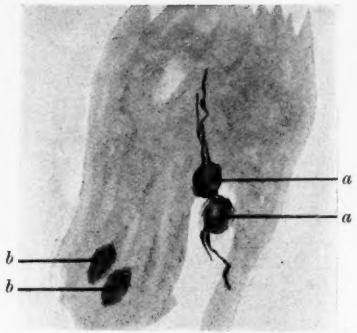


FIG. 6.—S.-A. node, monkey. Two nerve fibrils surrounding nuclei (*a*) in their course. The nuclei (*b*) are muscle nuclei. (Silver, L. oc. 4, obj. $\frac{1}{12}$.)

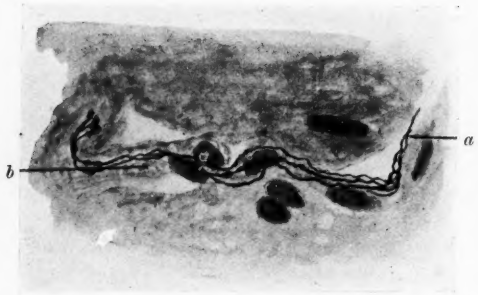


FIG. 7.—S.-A. node, monkey. Nerve fibril breaking up at (*a*) upon a muscle fibre; (*b*) the nuclei are muscle nuclei. (Silver, counter-stained with safranine, L. oc. 4, obj. $\frac{1}{12}$.)

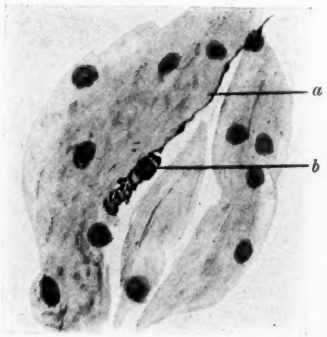


FIG. 8.—S.-A. node, monkey. Nerve fibril breaking up at (*a*) to surround a nucleus at (*b*). (Silver, counter-stained safranine, L. oc. 4, obj. $\frac{1}{12}$.)

FIG. 9.—S.-A. node, monkey. Nerve fibre forming a spiral round a group of nuclei. (Silver, L. oc. 4, obj. $\frac{1}{12}$.)

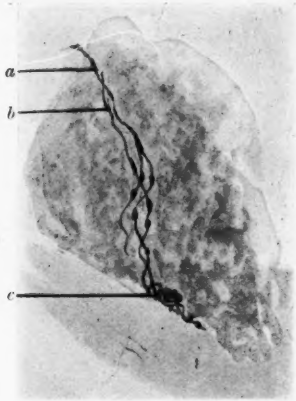


FIG. 10.—S.-A. node, monkey. Nerve fibrils (*a*) and (*b*) ending round a muscle nucleus at (*c*). (Silver, L. oc. 4, obj. $\frac{1}{12}$.)

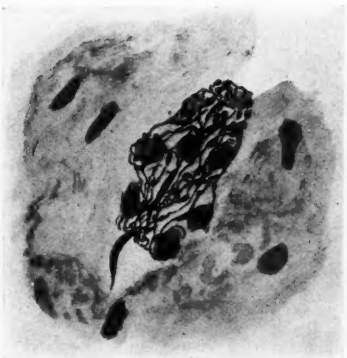

FIG. 11.—S.-A. node, monkey. Nerve fibril forming a network round a large group of nuclei. (Silver, counterstained safranine, L. oc. 4, obj. $\frac{1}{12}$.)

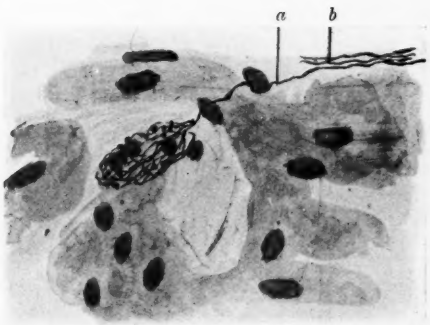


FIG. 12.—S.-A. node, monkey. Nerve fibril (*a*) coming from small nerve (*b*) to break up around a group of nuclei, probably muscle nuclei. (Silver, counterstained safranine, L. oc. 4, obj. $\frac{1}{12}$.)

small fibre sometimes breaks up in its course into a complex network, showing varicosities at the terminations and in the course of the fibrils. Sometimes several fibres combine in forming such a network, from which fibrils are sent out into the surrounding muscle (fig. 13, p. 9). Such a network appears to be a "station" on the course of the fibre: the one shown at fig. 13 could be traced through five sections $7\mu$ thick.

No ganglion cells were found within the node.

In the human heart no nerve endings were found in the node. A number of nerves enter the node from the ganglia lying near it (fig. 14). These branch frequently, but, while quite small branches could be found among the muscle fibres, they could not be followed to ultimate terminations.

### The Nerves of the Auriculo-Ventricular Bundle.

In the monkey the Cajal method alone was used. The results here were less definite than in the sino-auricular node, although in some respects very similar.

A number of nerves enter the nodal part of the auriculo-ventricular bundle from ganglia lying at the back of the heart and in the inter-auricular septum. These nerves pass forward in the inter-auricular septum, receiving branches from small ganglia lying near their course, and enter the nodal part of the bundle. One of these nerves and a ganglion cell associated with it are shown at fig. 15, p. 9. In the node the nerves quickly break up into small branches and single fibrils which ramify among the muscle fibres (fig. 16, p. 9). The fibrils give off very fine branches, some of which surround nuclei in a manner similar to the simpler endings described above for the sino-auricular node. Some of these branches are shown at fig. 17, p. 10. The nucleus at (*a*) appears to have a small "tail" of muscle, and the nerve fibril forms a very close connexion with this cell.

Fine nerve fibres can be followed into the right and left branches of the bundle, where they form a very fine plexus. The fibrils are less numerous and finer than in the nodal part of the bundle, but their distribution is similar. Here again they break up to surround nuclei. Fig. 17 (p. 10) shows a strand of the plexus forming a spiral round a chain of nuclei. A single fibre from the plexus is shown in the same figure applying itself to a muscle cell.

A branch from the plexus is shown at fig. 19, p. 12 (at a higher magnification), breaking up into numerous fine terminal filaments round a group of relatively small muscle fibres. These terminal filaments are very minute, and can only be followed with the oil-immersion lens.

In the guinea-pig the nervous element is very much more conspicuous.

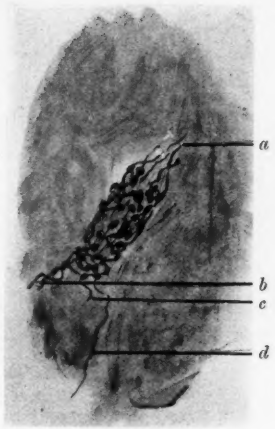


FIG. 13. — S.-A. node, monkey. A "station" in the course of a leash of fibrils. The fibrils enter at (*a*); fibrils (*b*), (*c*), and (*d*) pass off into the surrounding muscle. (Silver, L. oc. 4, obj. $\frac{1}{12}$.)

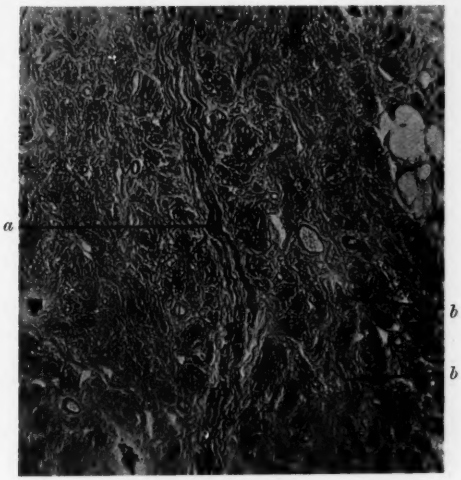


FIG. 14.—S.-A. node, human. Nerve (*a*) passing through the node Two small branches are shown at (*b*). (Silver. × 300.)

FIG. 15. — Auriculo-ventricular bundle, monkey. Nerve entering the nodal part of the bundle. (*a*) Nerve cell. (Silver. × 300.)

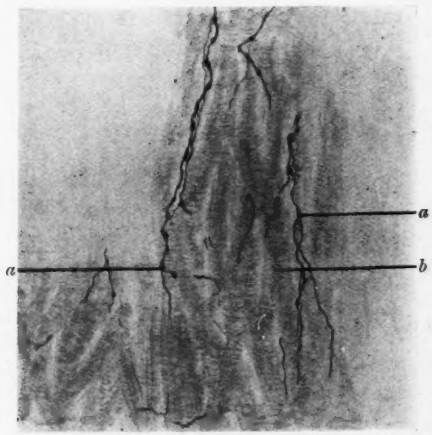


FIG. 16.—Auriculo-ventricular bundle. Nerves in the nodal part breaking up at (*a*) into five branches among the nodal muscle (*b*). (Silver. × 300.)

Large nerve strands enter the bundle through the inter-auricular septum. These nerves come from ganglia lying at the posterior part of the inter-auricular septum, as in the monkey's heart. Similar large strands of nerve fibres were found in all the hearts examined arising from these ganglia and running forward in the inter-auricular septum to enter the bundle in its auricular part. On entering the bundle the nerves break up quickly into larger and smaller strands. Many spread out upon the sheath of the bundle

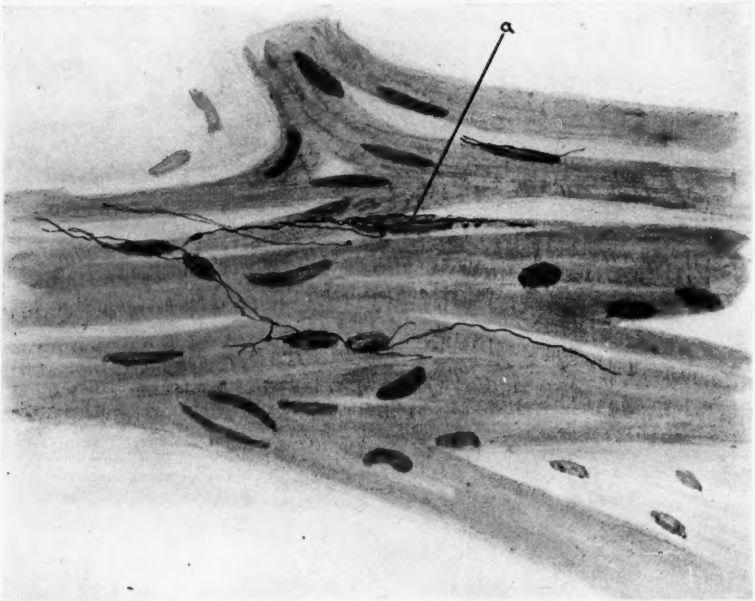


FIG. 17.—Auriculo-ventricular bundle, monkey. Terminal nerve filaments in the nodal part of the bundle. The nucleus at (*a*) has a small "tail" of muscle. (Silver. × 674 )

(fig. 20, p. 13): these are for the most part single varicose fibres or small strands of varicose fibres. Nerve fibres also accompany the muscle fibres or groups of muscle fibres and give off branches which course among them and form a plexus. Fig. 21 shows a plexus round a large cluster of nuclei lying in the meshes of the muscular network. Sometimes a single fibre gives off a brush of fibrils which apply themselves to a muscle fibre (fig. 22, p. 13). Occasionally a fibre was found surrounding a muscle cell in a spiral manner (fig. 22). A few small ganglia are present in the bundle: those found were in the left branch just below the bifurcation (figs. 23, p. 13, and 24 and

25, p. 14). The bundle in the guinea-pig breaks up early into small branches, and wherever a branch could be followed a nerve fibre or two were found accompanying it.

The above is a description of specimens stained by Cajal's silver method. Methylene blue showed the finer ramifications of the nerve plexus. Fig. 26, p. 14, is from a specimen stained by this method. Several strands of

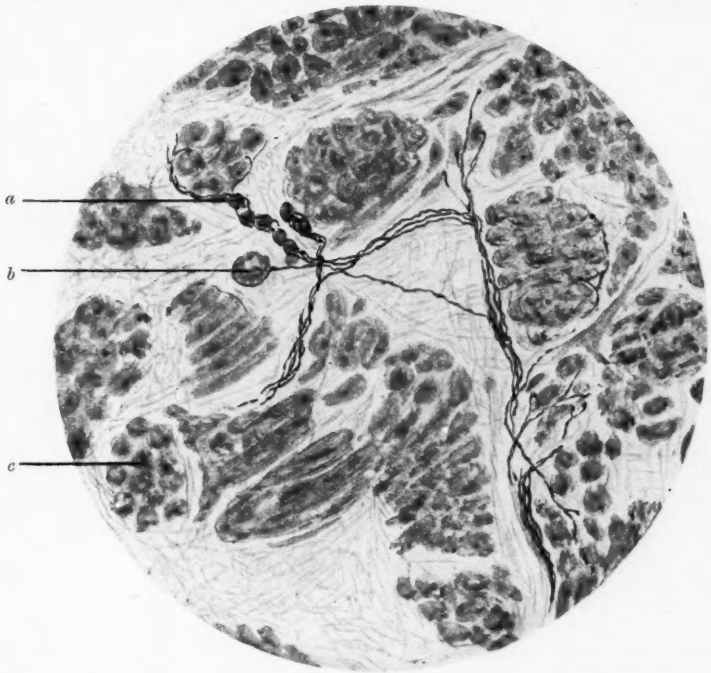


FIG. 18.—Auriculo-ventricular bundle, monkey. Nerve plexus in left branch of the bundle. The nerve filaments break up round a chain of nuclei at (*a*); at (*b*) a single filament is surrounding a muscle cell; (*c*) bundle muscle. (Silver. ×400.)

muscle fibres are shown surrounded by a very delicate plexus of varicose fibrils. The fibrils seem to form a very close connexion with the nuclei of the muscle-cells. There are no very definite "endings": the plexus appears to be continuous and merely to halt in its course to form an elaborate relation with these nuclei.

In the rat, as in the other animals examined, large nerves were traced entering the bundle from the ganglia at the back of the heart, by way of the inter-auricular septum. In the case of the rat nerves were also seen

entering the bundle after its bifurcation. Fig. 27 (p. 15) shows some large strands entering the right branch.

The bundle muscle of the rat is much more compact than that of the guinea-pig, and, consequently, it is much more difficult with silver staining to determine the distribution and termination of the numerous nerve fibres which surround the bundle and penetrate its substance. Specimens stained

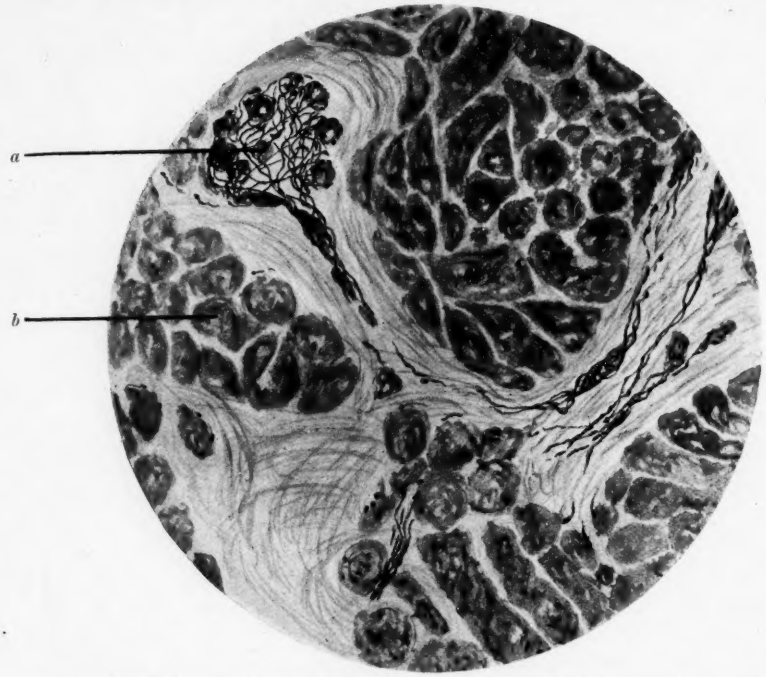


FIG. 19.—Auriculo-ventricular bundle, monkey. A terminal arborisation round a group of relatively small muscle fibres (*a*); (*b*) ordinary bundle muscle. (Silver. ×750.)

with methylene blue show the finer ramifications of the fibres which surround the strands of muscle. Fig. 28 (p. 16) shows the termination of a single nerve fibril.

It would appear that the nerve fibres in the rat are rather less numerous than in the guinea-pig, and their arrangement is less plexiform (fig. 29, p. 17). Fibres break up among the muscle fibres and form fine filaments which branch repeatedly and end in close relation with muscle cells (figs. 28 and 30, pp. 16, 17).

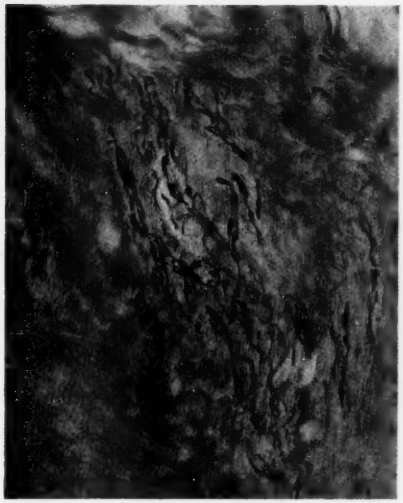

FIG. 20.—Auriculo-ventricular bundle, guinea-pig. Nerve fibres spreading out upon the sheath of the bundle. (Silver, L. oc. 1, obj. 6.)

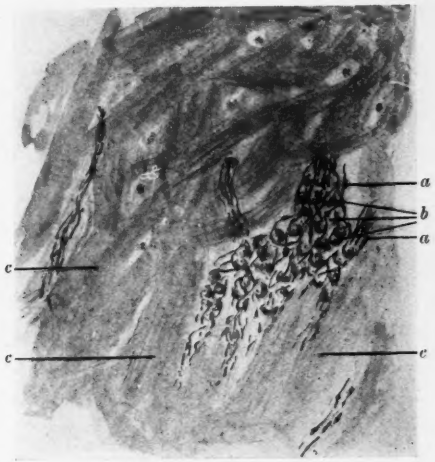


FIG. 21.—Auriculo-ventricular bundle, guinea-pig. Plexus of nerve fibres (*a*) round nuclei (*b*), and passing on to bundle muscle (*c*). (Silver, L. oc. 1, obj. 6.)

FIG. 22.—Auriculo-ventricular bundle, guinea-pig. Nerve fibre (*a*) breaking up into a brush of fibrils (*b*) in a muscle cell; (*c*), (*d*) another muscle cell of the bundle; (*e*) fibril coiled spirally round a small muscle cell. (Silver. × 300.)

FIG. 23.—Auriculo-ventricular bundle, guinea-pig. A strand of varicose fibres (*a*) in the bundle; (*b*) ganglion cell; (*c*) bundle muscle. (Silver. × 300.)

FIG. 24.—Auriculo-ventricular bundle, guinea-pig. A single ganglion cell (*a*) with pericellular network from fibrils (*b*); (*d*) bundle muscle; (*c*) strand of large fibres. (Silver. ×400.)

FIG. 25.—Auriculo-ventricular bundle, guinea-pig. Small ganglion (*a*) with uni- and bi-polar cells (*b*); (*d*), bundle muscle. From the left branch just below the bifurcation. (Silver. ×400.)

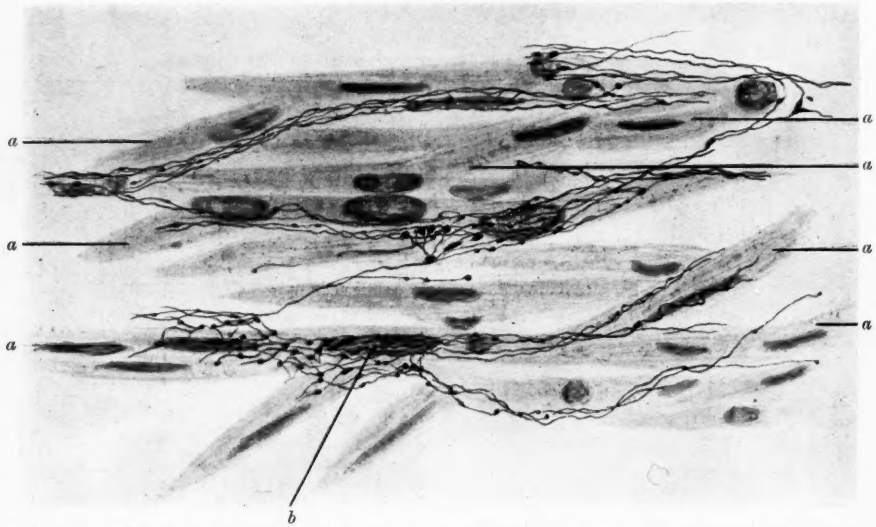


FIG. 26.—Auriculo-ventricular bundle, guinea-pig. Fine plexus of nerve fibrils round muscle cells (*a*) of the bundle. The nucleus (*b*) has a specially close development of fibrils. (Methylene blue, counterstained safranine. ×800.)

Specimens of the auriculo-ventricular bundle in the cat's heart show only scanty nerve fibres. A few strands were found entering the node and coursing for some distance in the bundle. Some of these break up and send filaments among the adjacent muscle fibres, but no extensive innervation was found.

The results for the human heart were similarly disappointing. Only a few small fibres were found in the bundle, nothing of the nature of a nerve plexus or nerve endings.

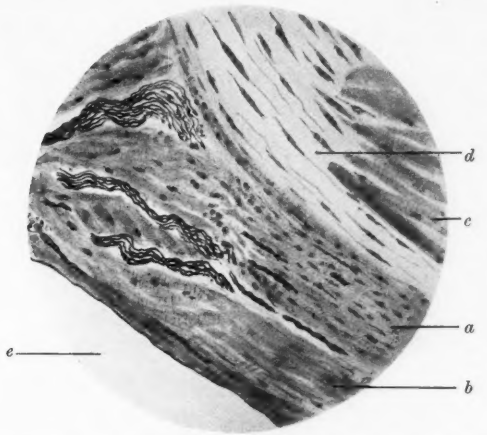


FIG. 27—Auriculo-ventricular bundle, rat. Nerves entering the right branch from the inter-auricular septum. (*a*) right branch of bundle; (*b*) auricular muscle; (*c*) ventricular muscle; (*d*) central fibrous septum; (*e*) cavity of right auricle. (Silver. ×200.)

The failure to demonstrate more than a few nerve fibres in human hearts and in those of carnivora may have been due to non-success of the staining, but, as the adjacent ganglia and the nerve fibrils around their cells were well stained in most of the specimens, such an explanation may not hold Further investigations on the subject are being carried out.

## SUMMARY.

(1) The nervous constituent of the nodal tissue of the heart is a very variable one in different mammals.

(2) In all the animals examined there are ganglia in close relation with both the sino-auricular node and the auriculo-ventricular bundle. Ganglia lie in the immediate vicinity of the sino-auricular node and

send numerous fibres into it, while the auriculo-ventricular bundle is connected with the ganglia in the posterior part of the inter-auricular septum

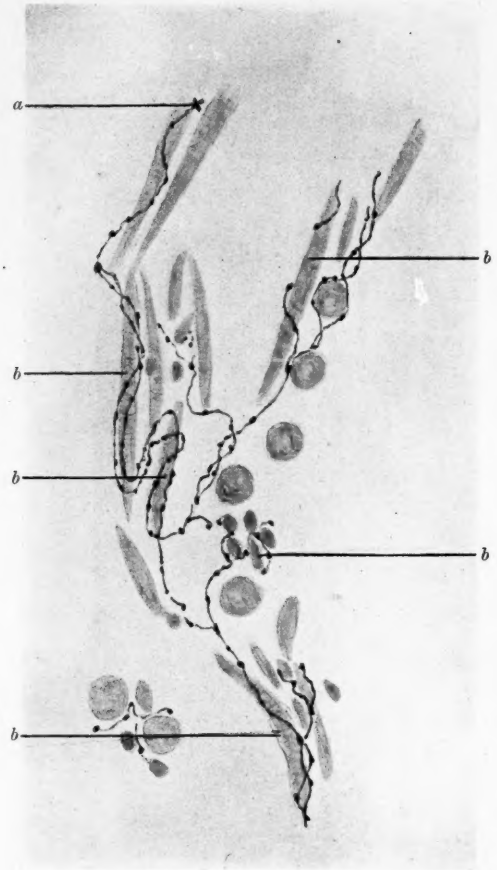


FIG. 28.—Auriculo-ventricular bundle, rat A single nerve fibril (*a*) branching to surround a number of muscle cells (*b*). (Methylene blue. ×800.)

through nerves passing forward in that septum to enter the bundle in its auricular portion.

(3) In the monkey the sino-auricular node has a rich nerve-supply.

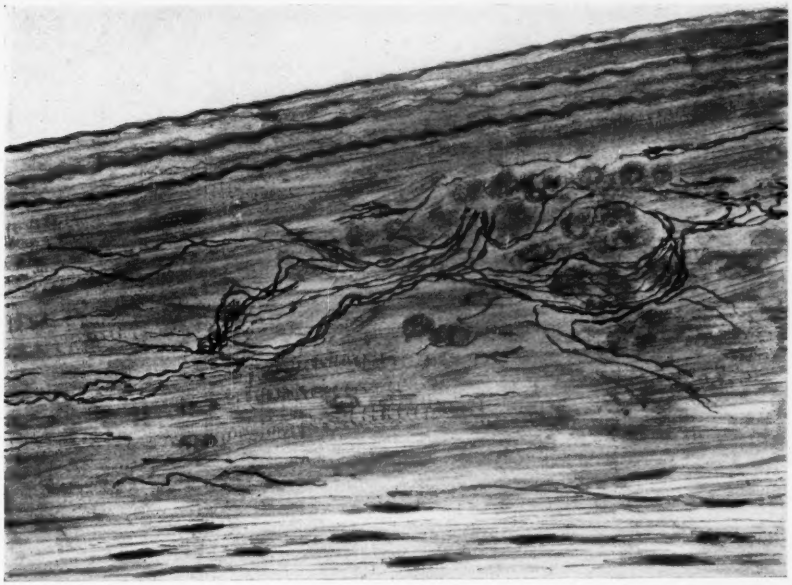

FIG. 29.—Auriculo-ventricular bundle, rat. Nerves breaking up among the muscle fibres of the bundle, left branch. (Silver. ×300.)

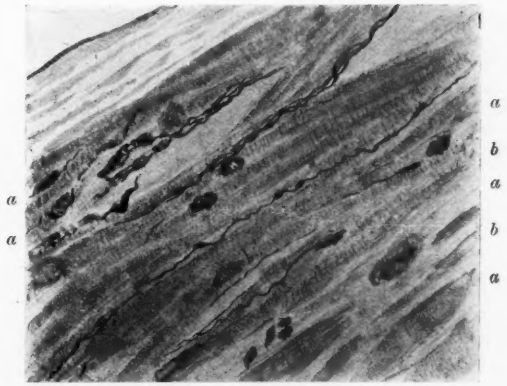


FIG. 30.—Auriculo-ventricular bundle, rat. Nerve fibrils (*a*) applied to the muscle fibres; (*b*) muscle nuclei. (Silver. ×400.)

The node contains highly specialised nerve endings quite distinct from those of ordinary cardiac muscle.

(4) The auriculo-ventricular bundle in all the hearts examined, except those of man and carnivora, has an abundant nerve-supply. This nerve-supply is a striking feature of the bundle in ungulates and in the guinea-pig and rat. In the monkey it is very much finer, but appears to be of a special character. In carnivora the nerve-supply appears to be scanty. The same is true of the human heart, although how far this appearance is due to the uncertainty of the special stains used for peripheral nerves is doubtful.

In conclusion, I wish to express my indebtedness to Dr James Ritchie, superintendent of this laboratory, at whose suggestion and under whose guidance this research was undertaken and carried out. Also to Dr W. T. Ritchie and Dr J. W. Dawson for much kind help in the course of the work. My thanks are also due to the Carnegie Trust for a grant towards the expenses of publication.

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# RECONSTRUCTION IN MODELLING CLAY: A RAPID METHOD OF PLASTIC RECONSTRUCTION FROM SERIAL SECTIONS.

By DAVID WATERSTON, M.A., M.D.

THE method of plastic reconstruction described below was worked out in my laboratory during last winter. Its usefulness was tested by preparing models of a variety of objects, such as the external form of two embryos, the central nervous system, and the pharynx and its pouches in the embryo, and the results obtained were quite satisfactory.

The method appears to be a modified form of the "free modelling" which was employed by W. His in the preparation of the series of models, now universally known, illustrating the development of the human embryo and of the chick—a method which His strongly recommended for embryological work up to the last, when many other workers were using the wax-plate method of Born.

Peter's criticism of His' method (1) is that it demanded an unusually high "technical" equipment in the worker, and that it afforded possible sources of error, since only individual points were given of the outline of sections.

I am inclined to think that His' method was not followed by the workers who succeeded him largely because the additional modifications and improvements introduced into the wax-plate method, and especially the addition of "ritzer" lines for guidance, gave that method an accuracy which could not be attained by His' original method, which was used without such aids.

The method which I have worked out meets the requirements essential in any satisfactory reconstruction method, inasmuch as it depends upon exact technique and upon measurements, and is therefore independent of the personal factor in the reconstructor. It has the great advantage that a satisfactory model can be produced in a fraction of the time required by the wax-plate method. It is applicable to practically any degree of enlargement, though it is more suitable for the production of a large-sized model than of a small one.

A high degree of technical or artistic capacity in the modeller is not essential, and I believe that the amount of error in the model prepared by this method can be reduced to as small an amount as is involved in

trimming the edges of wax-plates, a procedure which is necessary in Born's method, in order to remove the "terraced" appearance of the surface which is a result of that method, and which gives an erroneous idea of the surface.

In all its preliminary steps up to and including the drawing of the sections at a suitable magnification, the method follows exactly the same lines as the wax-plate method, and hence it is not necessary to describe these steps in detail.

Of the succeeding steps, perhaps the simplest description will be afforded by describing the procedure followed in preparing a model of the external surface of an embryo. Briefly stated, they consist in making a linear profile reconstruction of the median sagittal section of the embryo, and

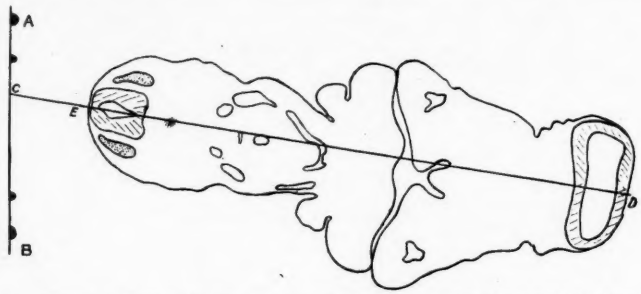


FIG. 1.—Section of human embryo, with orientation line A B, median sagittal plane C D.

then building up, upon the outline so obtained, first one half of the embryo and then the other half, in modelling clay.

1. *Linear Reconstruction of the Median Sagittal Section.*—To those who are familiar with all the methods of linear reconstruction, this procedure presents no difficulty.

It is only necessary to bear in mind that as the embryo is asymmetrical in the majority of cases, the median plane of the embryo in the section drawings does not coincide in all cases with the line of the median sagittal section.

The difficulty involved in this is overcome in the following way. The drawing of a typical section is taken, and upon it the line of the median axis of the embryo is drawn (fig. 1, E D). This axis is prolonged to meet the "orientation" line, which it intersects at the point C.

On the drawings of each of the other sections a line is then inserted similar to the line C D, that is, it begins at the point C on the orientation line, and is at the same angle to the orientation line A B.

The simplest way of doing this is to copy the "ritzer" line and the line C D on tracing paper, and then to superimpose and copy the tracing on the other section drawings.

Figs. 2 and 3 show how such a line falls in some of the other sections.

In making the linear reconstruction, the line C D is used in all sections, and the distances C E and C D are used to obtain the outline required (fig. 4).

2. *Building up the Model.*—The linear reconstruction on millimetre paper is fixed to a flat board, and a thin sheet of glass is placed on it. Modelling clay is then placed on the glass plate and distributed over the outline and moulded exactly to the margin of the subjacent reconstruction. Then, beginning at the head or tail end, the surface of the clay is moulded

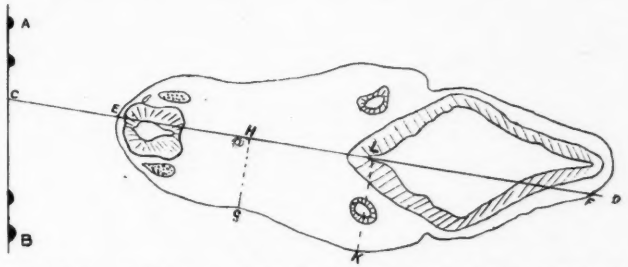


FIG. 2.—Section of embryo, with the orientation line A B, and the line C D, which gives the plane of the mesial sagittal section of the whole embryo at this level.

to the surface contour of the outline of each section. At first it is not necessary to take every section, but every fifth or tenth section. The procedure will again be explained most simply by a concrete example.

Suppose the line E F in fig. 4 is the level of the section in fig. 2; then the surface of the clay along that line is to be moulded to the outline E G K F in fig. 2.

This is done by measuring lines such as G H and K L and levelling the clay at these points to that height.

A sufficient number of points must be taken to ensure that the elevations and depressions of the surface are correctly represented.

An instrument like a knitting needle is employed, the length of G H, L K, etc., measured off on it, and the instrument is plunged into the modelling clay at the corresponding point, and the clay at these points is raised the required level.

When the principle is grasped, there is not the slightest difficulty in carrying out its practical application, and individual workers can easily

devise suitable instruments for helping them in special points. One or two differently shaped modelling tools, of metal or wood, are useful.

After the first rough outline has been obtained, the model is again revised, using every section if the outline varies appreciably from section to section, until an accurate result has been obtained.

3. *Making the Permanent Model.*—The clay model is then embedded in plaster of Paris, a uniform thickness of plaster being spread over the surface to a depth of from half to one inch.

After it has set, the plaster case containing the clay model is lifted off the glass plate, and turned over.

On the surface now exposed there is the outline in clay of the median sagittal section, and a plaster case surrounding it.

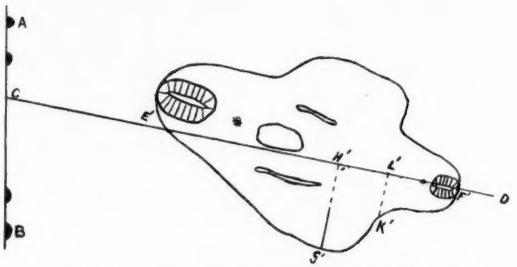


FIG. 3.—Section of same embryo near tail end showing how the line C D falls in this case.

The clay surface can be treated in a variety of ways.

If a complete model of the whole embryo is required, the outline contour is built up in clay in practically the same way as before, the level of the various sections being easily identified, and the level of the plaster being used instead of the glass plate to measure the depth.

It may also be used as a basis for modelling, in relief, the cavities of the body, or as a basis for building up some selected structures, *e.g.* pharynx, heart, etc.

There is no special difficulty in carrying out either of these alternatives, but it is important to have a clear idea of what structures it is desired to include in the model before starting.

After this side has been finished, it is also embedded in plaster. There is therefore now a complete plaster mould from which casts can be taken, in plaster or other medium, and painted as desired.

The details of the plaster casting differ in no way from the ordinary steps.

One or two practical details may be added.

Modelling clay is cheap, and can be obtained from dealers in artists' materials. To keep it moist, it should be placed in a large jar, and covered with a damp cloth.

The surface of the glass plate should be rubbed over with vaseline before the plaster of Paris is put on it, to prevent the glass and plaster adhering.

Modelling tools of different shapes can be obtained from ironmongers or artists' dealers. One with a flat, curved end is useful.

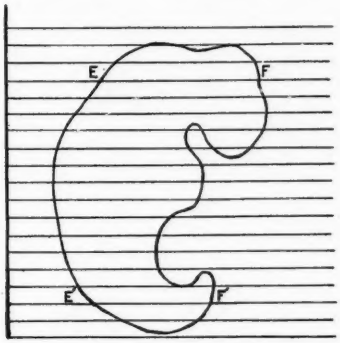


FIG. 4.—Linear profile reconstruction of median sagittal section from horizontal sections.

A model of a portion of an embryo can be easily made, by exactly the same method,—using the outline on the sagittal section of that portion only, and measuring its diameters from section to section.

Dissectible models cannot be easily prepared by this method, except by a somewhat lengthy process, but the advantage of the method is that it affords a rapid means of obtaining an accurate plaster model of any structures which one may desire to see in the solid, with their relations to adjacent structures.

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# CONGENITAL ANOMALIES OF THE FIFTH LUMBAR VERTEBRA AND THEIR CONSEQUENCES.

By J. Appleton Nutter, B.A., M.D., C.M., *Montreal.* (*From the Department of Anatomy, McGill University.*)

The vertebral column has of late years proved of increasing interest to the surgeon. With the perfecting of the X-rays has come much greater opportunity for study, and congenital anomalies are known to play a far more important rôle in the consideration of the spinal column than would have been conceded but a few years back. The anatomy of the last lumbar vertebra and of the lumbo-sacral articulation has in the opinion of the writer not received the attention it merits. A careful study of numerous X-rays of the lumbar spine has on many occasions revealed perplexing conditions, which have been cleared up only by attention to the vertebral embryology and its variations. It was with the hope of adding to our knowledge of this region of the spine that the present study was undertaken.

Attention must be drawn to the insecurity of the lumbo-sacral articulation. In the erect position of the body this has a downward and forward inclination of some 30°, thus furnishing a strong tendency for the heavy trunk to slide downwards into the pelvis. To add to the insecurity due to gravity, one finds free movement at this part of the vertebral column. Such movement is made possible partly by changes in the intervertebral substance, which, bearing as it does the weight of the body, is nevertheless not flattened out by the superincumbent weight. With its semi-solid nucleus under great pressure it resembles a water-pillow. If it, however, permits free movement for the spine, it does not afford a corresponding amount of security. Nor are the various ligaments which bind the last lumbar vertebra to the sacrum in themselves of sufficient strength to prevent gradual displacement forward under the action of gravity. Indeed, almost the whole strength of the articulation depends upon the inferior articular processes, which are gripped firmly between the articular processes arising from the sacrum. A sliding of these two pairs of processes upon each other affords the main movement of the articulation. During forward bending of the trunk, the inferior articular processes move upward upon the sacral articular processes. This movement in itself, if carried beyond

normal limits, can result in a dislocation of either one or both articular processes, with consequent forward displacement of the vertebra. Such a forward displacement of the body alone or of the entire fifth lumbar vertebra is termed spondylolisthesis.

It will be remembered that the general rule for vertebral ossification calls for three primary centres, which appear toward the end of the second month of fœtal life. One is for the main part of the vertebral body; the remaining two form the two halves of the neural arch, with a small portion of the body. Soon after puberty a number of secondary centres appear which do not become wholly united before the twenty-fifth year. The neural arch of the fifth lumbar vertebra is said to have normally two centres of ossification in each half, the line of division passing between the superior and inferior articular processes. This point marks the spot where laminar deficiency is to be found, as is well shown in all the specimens.

It is in the comparison of parts known in human anatomy under the general name of transverse processes that the main difficulty of establishing homologies exists. The transverse processes of the cervical vertebræ possess a foramen which in all but the seventh transmits the vertebral artery. If we examine a cervical rib we shall see that the foramen is still there, and that it separates the rib, which lies in front of it, from the transverse process proper, which lies behind. The part of a cervical transverse process in front of the vertebrarterial foramen is therefore generally admitted to correspond to the first part of a rib, while the part behind the foramen corresponds to the transverse process proper.

In the thoracic region the ribs articulate with the transverse processes and lie in front of them. There are, however, no foramina here.[1] In the lumbar region the transverse processes are elongated, and it is held that their outer part corresponds with the first part of the ribs. No foramen is normally present here, as rib and transverse process proper are fused together. We shall, however, see that this foramen is at times found even in the lumbar transverse process, and that it is analogous to the cervical foramen.

The whole number of vertebræ may be diminished or increased by one. The first sacral, normally the twenty-fifth vertebra, may be the twenty-fourth or twenty-sixth. It is believed that such numerical variation is the result of an error in segmentation.

A want of development of the bodies, which may be only half the normal height on either or both sides, is found almost exclusively in the lumbar region. Such a condition has most far-reaching results when an asymmetrical vertebra is formed at the lumbo-sacral junction. In such

[1] A foramen in this part of the twelfth thoracic vertebra is by no means uncommon.

case the vertebra in question may be either the fifth lumbar or a supernumerary vertebra. A case illustrative of this will be cited later. There may be an intermediate or transitional form, the so-called lumbo-sacral vertebra, in which one side is united to the sacrum and the other has a free transverse process as seen in a lumbar vertebra. The explanation of this is simple. The position and form of the sacrum depend upon the innominate bones which articulate with it. If the innominate bones become by chance asymmetrically placed, a vertebra may show sacral characteristics on the side where it articulates with the innominate, and a free transverse process where no such articulation exists.

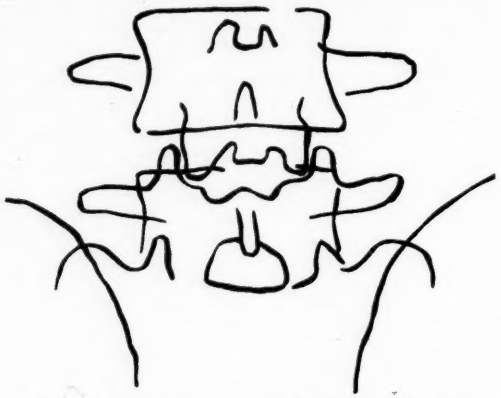

Fig. 1.—Tracing of skiagram of normal lumbo-sacral junction. Last two lumbar vertebræ, upper portion of sacrum, and adjoining iliac crests shown.

Anomalies of the last or fifth lumbar vertebra may be classified, as has been suggested by Manners-Smith (*Journal of Anatomy and Physiology*, vol. xliii.), under four headings, which we shall increase to eight.

### 1. Foramina in relation to the Transverse Process.

Under this first heading we have to deal with anomalous foramina in and near the transverse processes. That most frequently seen is one behind the root of the transverse process and close to the superior articular process. This seems to agree exactly with a retrotransverse foramen found in the sacrum of the ornithorhynchus. A nearly complete foramen of this type can be seen in the specimen from the M'Gill Museum of Anatomy showing defective ossification of one lamina.

The foramen (fig. 2), however, which primarily interests us is one by

which the transverse process is pierced near the middle of its root. This foramen is without doubt analogous to that seen normally in the transverse processes of the cervical vertebræ. It will be remembered that this cervical foramen is considered to divide the transverse process into its own component

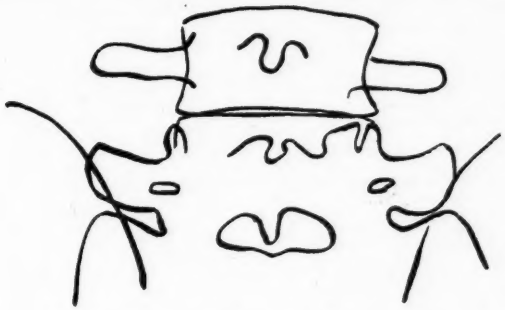

FIG. 2.—Fifth lumbar vertebra shows sacralisation of transverse processes, which show foramina in their roots. Strikingly suggestive of cervical foramina.

parts, the rib element being anterior. It is not, therefore, an undue assumption on our part to conceive of this foramen in the lumbar transverse process as pointing to its twofold origin, in that it originally was made up of rib and transverse process.

### 2. BIFURCATION OF THE TRANSVERSE PROCESS (figs. 3 and 4).

This differentiation or resolution of the transverse process into its component parts is much more plainly seen when carried to the extent of actual bifurcation of the process. The gap shown is merely an enlarged foramen, which separates the true transverse process above from what corresponds to the rib below. The latter may and often does articulate or even fuse with the sacrum. Such bifurcation may vary in extent from a mere suggestion to the well-marked specimen shown in one of the X-ray tracings.

### 3. ENLARGEMENT OF THE TRANSVERSE PROCESSES, SO-CALLED SACRALISATION (figs. 4 and 5).

One of the commonest anomalies seen in the fifth lumbar vertebra is the so-called sacralisation. By this term is meant that the transverse processes are much increased in size, most unlike the ordinary lumbar transverse processes, and resemble the lateral masses of the sacral segments.

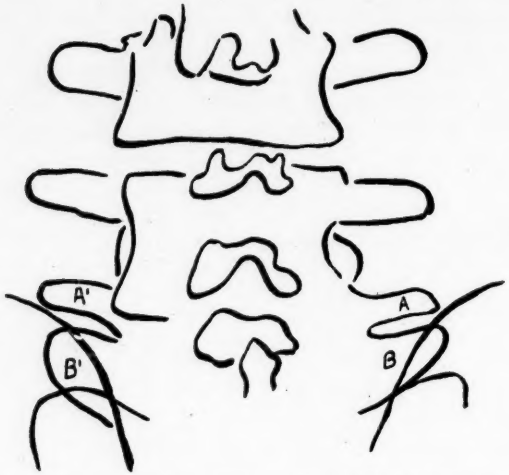


FIG. 3.—Bifurcation of the transverse processes of last lumbar vertebra, with resolution into costal elements (A and A′) above, and transverse elements (B and B′) below, the latter articulating with sacrum and probably with iliac crests.

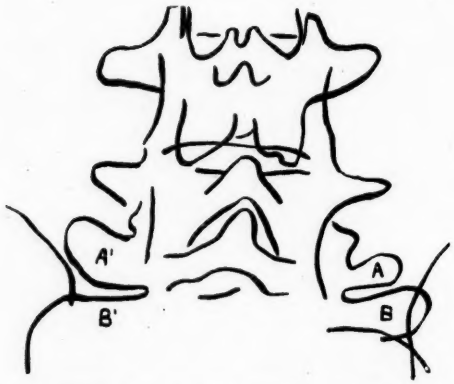


FIG. 4.—Asymmetry at lumbo-sacral junction. A and A′, the costal elements of the fifth pair of lumbar transverse processes, correspond, as do B and B′, the corresponding transverse elements. B′ has become sacralised owing to the higher position of the innominate bone of that side, and is shown fused with the sacrum. B, on the side of the more caudally placed innominate bone, remains separate, though articulating with the sacrum.

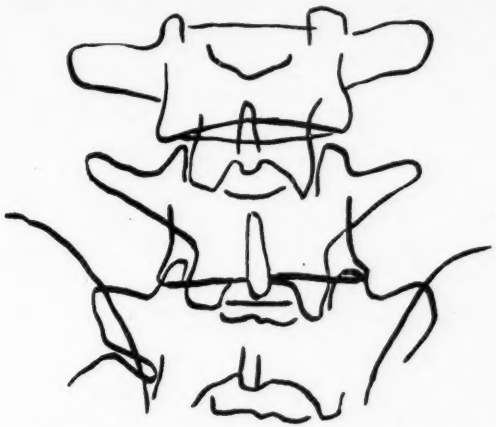

FIG. 5.—Shows relatively common overgrowth of the transverse processes of the last lumbar vertebra (so-called sacralisation). Note the short, thick processes, that on the left side at least articulating with the sacrum.

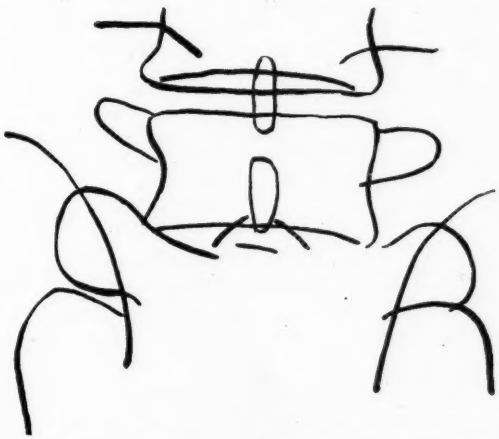

FIG. 6.—Shows marked sacralisation of the transverse processes of the fifth lumbar vertebra, with abnormal articulation with the sacrum on the right.

Such a change is very common indeed, and when one-sided has been mistaken in the X-ray for some pathological condition.

### 4. Abnormal Articulation with the Sacrum and Ilium (figs. 3, 6, 7).

Another anomaly to be mentioned while speaking of the transverse process is that of its articulation or fusion with the ala or lateral portion of the sacrum. This articulation is frequent and distinct, and was named the "lumbo-sacral transverse articulation" by the late Professor Dwight of Harvard University. A transverse process can articulate with the sacrum,

Fig. 7.—Both transverse processes sacralised. Both articulate with sacrum, and probably with iliac crests. Congenital imperfection of neural arch, with failure to unite posteriorly.

or even with the iliac crest, without having assumed sacral characteristics. This, however, is uncommon, and is unlikely to be congenital—rather acquired. It is generally in the case of sacralised transverse processes that we find abnormal articulation with the sacrum, and in some instances even fusion.

From the surgical view-point we may consider such enlargements of the transverse processes as of importance almost wholly confined to the production of scoliosis. Z. B. Adams in the *Journal of the American Orthopedic Association* for November 1910 reports such an instance. In his case the patient, a young girl, suffered from scoliosis. This was by X-ray shown to be caused by the impinging of a partly sacralised trans-

verse process against the ilium or sacrum, thus forcing the vertebral column to the other side. Removal of the offending process gave immediate and marked improvement.

It is probable also that such an impinging, if repeated, might be the cause of a persistent pain in the back or referred to the region of the sciatic nerve. A bursa, which if inflamed would produce characteristic disturbance, would naturally be formed at the site of this abnormal articulation.

### 5. Asymmetry of the Body of the Vertebra.

Such a condition has been already noted to occur almost exclusively in the lumbar region. There may be practically complete absence of one

Fig. 8.—Asymmetry of the neural arch of the fifth lumbar vertebra, the two laminæ having very different appearances. In a traumatic case this skiagram might easily be mistaken to indicate fracture of the neural arch.

lateral half of the body. When found at the lumbo-sacral junction the asymmetrical body may be that of the fifth lumbar, or may be supernumerary. Joachimsthal in the *Deutsche medizinische Wochenschrift*, 15th September 1910 ("Ueber angeborene Wirbelanomalien als Ursache von Rückgratsverkrummungen"), reports a case of congenital scoliosis in a child of three years. The lumbar spine was inclined to the right. An X-ray revealed the cause to be a supernumerary half-vertebra interposed between the fifth lumbar and the sacrum. This was developed only in its left half, which naturally had the effect of tilting the spinal column to the right. In addition the body of the fifth lumbar vertebra showed marked diminution of its left half, and that of the fourth the same deformity to a

slight extent. The X-ray apparently showed no trace of any other portion of the supernumerary vertebra save that of its body.

6. Imperfect Ossification of the Laminæ (figs. 9, 10, 11, 13).

All these anomalies so far discussed, though potentially productive of scoliosis and back or leg pain, are unlikely to offer a menace to life. We now, however, come to an anomaly that is of vital importance to all of us, namely, imperfect union of the laminæ, the result of unfinished ossification of the neural arch.

The instability of the lumbo-sacral articulation has already been pointed out. The importance of the articular processes in affording secure anchorage to the vertebral column has been demonstrated. It has been shown that

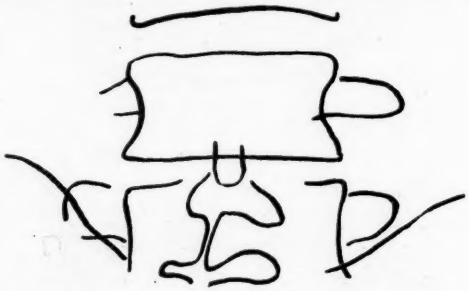

Fig. 9.—Ossification defect in the left lamina of the fifth lumbar vertebra, with failure of the neural arch to unite. Laminar asymmetry well marked. Analogous to spina bifida, but easily mistaken for fracture.

each side of the neural arch has two centres of ossification, and that these meet one another at a point between the two articular processes. When deficient laminar ossification occurs, and it is most commonly bilateral, the body of the vertebra rests most insecurely upon the sacrum, and must trust to frail supports—mainly the intervertebral substance—to keep it from sliding downward and forward over the promontory and into the pelvis.

The pictures are here shown of a specimen (fig. 12) now in the M'Gill Pathological Museum. The case was reported by Dr A. H. MacCordick and the writer in the *Journal of the American Orthopedic Association* for November 1912. It was known to many at the Montreal General Hospital. A young Englishman was struck down by a blow in the back from a falling beam. His back was broken and his spinal cord crushed. After two years of suffering it was at post-mortem discovered that this man's fifth lumbar

vertebra had been imperfectly ossified (fig. 13). His laminæ, as can be seen, were incomplete, the anchorage at his lumbo-sacral articulation was

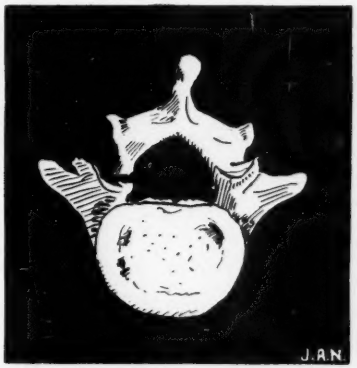


FIG. 10.—Fifth lumbar vertebra from M'Gill University Museum of Anatomy showing unilateral ossification defect between superior and inferior articular processes.

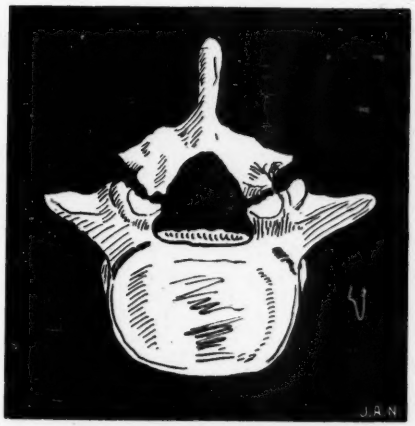


FIG. 11.—Fifth lumbar vertebra from M'Gill University Museum of Anatomy showing double ossification defect in the interarticular portions of the neural arch.

thereby weakened, and the blow upon his back was sufficient to drive forward the last lumbar vertebra upon the sacrum, producing spondylo-

FIG. 12.—Case of traumatic spondylolisthesis. Note displacement forward of body of fifth lumbar vertebra, due to weakness of its neural arch through imperfect ossification. Fifth lumbar vertebra shown in fig. 13.

listhesis and crushing of the spinal cord. It is quite possible, if not probable, that in his case the blow might not have produced such fatal results had his fifth lumbar vertebra been of normal strength in all its parts. Statistics are not at hand to determine how many of us are going through life with spines imperfectly ossified, awaiting the blow that when directed against our weakened laminæ shall at once break our backs. Two other specimens of congenital deficiency in the neural arch are to be found in the Anatomical Museum of M'Gill University. In one specimen the deficiency is bilateral, as is more common. The other shows it upon one side only.

Do not suppose that the evil effects of a congenitally weakened vertebra

FIG. 13.—Fifth lumbar vertebra from case of traumatic spondylolisthesis. Note imperfection of both halves of neural arch, leading to displacement forward of the body and partial fracture of the left pedicle.

are to be seen as the result of sudden and violent trauma alone. A study of the deformity produced by a displacement of the body of the fifth lumbar vertebra forward upon the sacrum (so-called spondylolisthesis) was recently undertaken. Such a deformity narrows markedly the inlet of the pelvis, offering a serious impediment to labour. Its study hitherto has been largely confined to the members of the obstetrical faculty. An inquiry into its ætiology has proved most interesting in the light of the subject now under consideration. Here, again, we find that a congenitally imperfect neural arch is by far the commonest cause of the displacement forward of the spine. The existing weakness of the anchorage is, however, increased by the softening of the ligaments incident to menstruation and pregnancy. As a consequence, the body of the last lumbar vertebra becomes displaced forward by slow degrees. Trauma, no more severe than that associated

with heavy work, may be sufficient to produce spondylolisthesis, especially in women subjected to repeated pregnancies. It is thus seen that a weakened neural arch at this particular spot is a constant menace to its possessor, and to a much greater extent if the possessor be a woman.

### 7. Spina Bifida or Hydrorrhachis

is, as a rule, associated with defect not in one but in several adjoining vertebræ. Mention should, however, be made of this congenital malformation of the neural arches, with its accompanying hernia of the spinal membranes. As is well known, it is most commonly found in the sacral and lumbar regions. It is due to a more or less complete lack of closure of the spinal canal posteriorly. The neural arches may be partially or completely absent. When these are present in part it will be found that the lamina of either side has failed to unite with its fellow. In rare instances the sac is found to protrude between completely formed arches.

### 8. Congenital Changes in the Articular Processes.

Goldthwait ("Lumbo-Sacral Articulation," *Boston Medical and Surgical Journal*, 16th March 1911) insists upon the instability of the fifth lumbar vertebra, and its absolute dependence upon its inferior articular processes. Stress is laid upon variation in the articular processes themselves. There is, indeed, considerable movement of these upon the sacral articular processes, so that a small-sized process would not require much movement to become dislocated from its sacral anchorage. In like manner these processes afford much less stability when they resemble the dorsal articular processes in being directed antero-posteriorly instead of laterally. (See also Goldthwait, "An Anatomic Explanation of many Cases of Weak Backs, etc.," *Journal of the American Orthopedic Association*, February 1913.)

# A CASE OF COMPLETE ABSENCE OF BOTH INTERNAL CAROTID ARTERIES, WITH A PRELIMINARY NOTE ON THE DEVELOPMENTAL HISTORY OF THE STAPEDIAL ARTERY.

By A. G. Timbrell Fisher, M.B., Ch.B., M.R.C.S., L.R.C.P., *Demonstrator of Anatomy and of Surgical Applied Anatomy, University of Bristol.*

Complete absence of both internal carotid arteries must be a very rare condition in man, as a careful review of the literature at one's command does not reveal any record of such an arterial anomaly, although a more thorough investigation might have brought to light instances of its occurrence.

The case to be described was noticed during the post-mortem examination of a man aged thirty-nine who died from cerebral hæmorrhage. Dr Scott Williamson, pathologist to the Bristol General Hospital, kindly sent the brain and part of the base of the skull with attached neck parts to the Anatomical Department of Bristol University for a more detailed examination of the condition present, and through the kindness of Professor Fawcett this duty devolved upon myself.

## Comparative Anatomy.

In Ruminants (8), of which the sheep may serve as a type, the internal carotid artery, properly so called, is absent. Its place in the cranium is taken by a small oval network lying at the side of the sella Turcica under the dura mater—the rete mirabile. There are three originating arteries of the rete as a rule. One of these, the spheno-spinous artery, arises from the internal maxillary at the same point as the inferior dental artery, and enters cranium through foramen ovale. The other two originating arteries arise from internal maxillary in common with the ophthalmic artery and pass backwards through a supra-sphenoidal canal. Towards the middle part and above, the rete reconstitutes itself into a trunk which traverses the dura mater and divides into the anterior, middle, and posterior cerebral arteries. In the ox the rete forms a more circular mass surrounding the sella Turcica; the occipital arteries assist in its formation.

In Carnivora such as the dog the internal carotid artery enters the carotid canal at its posterior opening, and, running forwards, leaves the

cranium at the carotid foramen by making a considerable bend. It then re-enters the cranium, having received a branch from the external carotid, and anastomoses on the side of the pituitary fossa with the spheno-spinous artery and returning branches of the ophthalmic artery. In this way a plexus is formed which probably represents the rete mirabile of Ruminants and Pachyderms, and from which the cerebral arteries proceed. The function of the rete mirabile appears to be to prevent cerebral congestion in grazing animals, whose heads are dependent for long periods.

In Fishes (9) two carotids, usually described as anterior and posterior, or as internal and external, can generally be seen arising on each side from the anterior afferent branchial arteries, although they are subject to a good deal of variation.

From Amphibia onwards, the internal and external carotids arise by bifurcation of the common carotid.

### Absence of a Single Internal Carotid Artery in Man.

Wyeth (1) mentions a case in which the left internal carotid artery was absent and no carotid canal was present. The anastomoses were not described. Wyeth calls attention to a somewhat similar case described by Eugene Peugnet (2), and states that a skull was seen by Koberwein with only one carotid canal.

Mrs Flemming (3) has recorded absence of the left internal carotid artery. In this case "three branches came off from the arch of the aorta, viz. innominate, left subclavian, and between them a small branch which had the distribution of the left external carotid. No internal carotid artery was present on the left side; on the right side the common carotid divided as usual. The arrangement of the arteries at the base of brain was as follows:—The right internal carotid divided into a right middle cerebral and a trunk which anteriorly divided into right and left anterior cerebrals. The basilar artery divided into the right posterior cerebral and a trunk three-eighths of an inch long which divided into the left posterior cerebral and left middle cerebral. The latter was connected by a slender branch with the left anterior cerebral, thus completing the circle of Willis." The ophthalmic artery on the left side arose from the middle cerebral. No carotid canal was present.

Quain, in his classical *Commentary on the Arteries*, describes a case of absence of the left internal carotid artery, and through the kindness of Professor Thane I have been able to examine the original specimen. To quote Quain's own words, on the left side (fig. 1) "the carotid artery furnishes the usual branches of the external carotid and divides into temporal and internal maxillary arteries. In the place of an internal

carotid, of which there is no trace, two tortuous branches derived from the internal maxillary join within the skull to form a single vessel which lies to the inner side of the fifth nerve. The artery so constructed being, however, smaller than the usual size of the internal carotid, the deficiency is compensated by the artery of the opposite side, which is of large size." This case is of more than usual interest because it is so similar to the condition present in Ruminants (*vide supra*). The single large trunk lying to the inner side of the fifth nerve occupies the position of the rete mirabile in the sheep, and the arteries springing from the internal

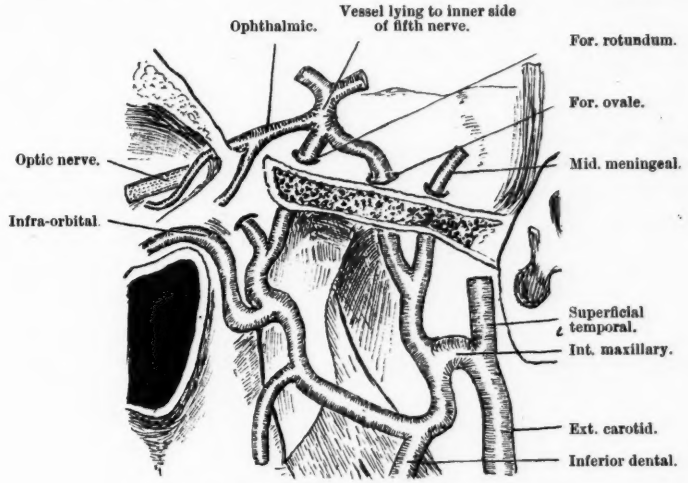


FIG 1.—Absence of left internal carotid (Quain).

maxillary and entering the cranium through the foramen rotundum and foramen ovale remind one quite forcibly of the originating arteries of the rete, which also spring from the internal maxillary.

Quain also refers to a case described by Tode (4) in which the right internal carotid was absent, and the carotid canal was very small—sufficient only "to allow the passage of a bristle."

In Wernitz's (5) list of cases, absence of the right internal carotid artery is mentioned associated with hydroanencephalus.

## CASE UNDER CONSIDERATION.

Turning now to the case under consideration, it may be mentioned in the first place that the condition did not lead to any symptoms during life,

although it may have hastened its end. Increased strain must have been thrown upon the artery which ruptured and caused death, owing to the abnormal features presented by the circle of Willis. The kidneys were arterio-sclerotic, but there was very little arterio-sclerosis evident in the arteries of the base of the brain.

*Arrangement of Cerebral Arteries* (fig. 2).

The basilar artery, nearly double its normal calibre, ended slightly to the right of the mesial plane at the upper border of the pons by dividing into

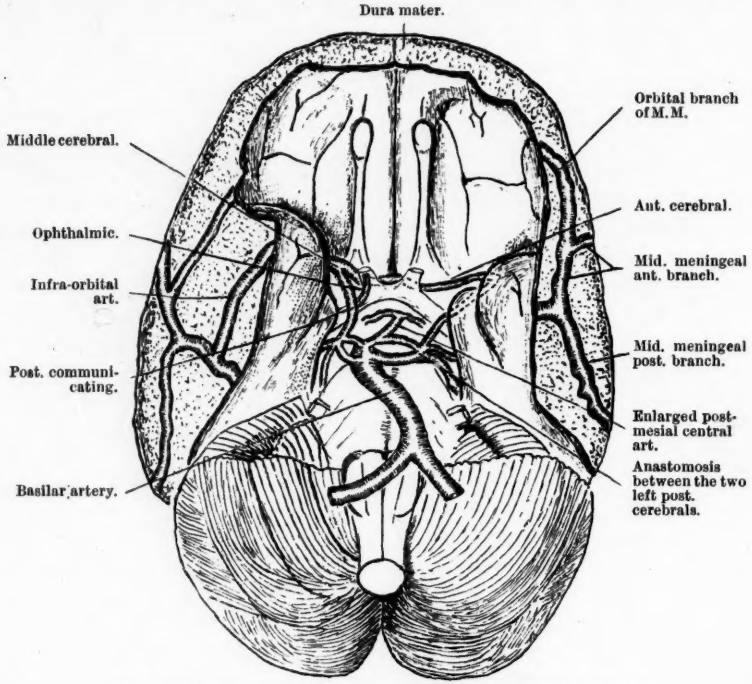


FIG. 2.—Absence of both internal carotid arteries. Showing arteries at base of brain and in dura mater.

the posterior cerebrals. A supernumerary posterior cerebral was given off just before the terminal bifurcation. The two left posterior cerebrals are longer and of greater calibre than those of the right side. On each side the two posterior cerebrals are joined together by anastomosis a short distance from their origin; they then divide and subdivide and form a wide-meshed

rete situated on the crus cerebri, which distributes the ordinary branches of the posterior cerebral. The distally situated posterior cerebral on the left side gives off an enormously enlarged postero-mesial central artery. This at first sight seems to be a continuation of the basilar; it divides into two branches which come off at right angles and enter the locus perforatus posticus. Subsequent dissection showed that they traversed the subthalamic region and finally entered the posterior part of the internal capsule, and it was evidently the rupture of this artery on the left side that caused death.

On each side, from the point of anastomosis of the two posterior cerebrals, a slender artery proceeds forwards and outwards, occupying the position of the posterior communicating artery in the normal brain. On examining transverse sections of these latter arteries, they were seen to be almost entirely occluded by concentric fibrosis. On the right side, however, the fibrosis occurs in that part which extends between the origin of the ophthalmic artery and the posterior cerebral. These slender arteries divide at the locus perforatus anticus, further out on the left side than on the right side, into anterior and middle cerebral arteries. The latter are joined by the anterior communicating artery, thus completing the circle of Willis. On the right side the common trunk of the anterior and middle cerebrals gives off an ophthalmic artery in the middle of its course, and both give off an anterior choroidal artery near their termination.

Antero-mesial and antero-lateral central arteries are given off in the usual way by the anterior and middle cerebral arteries, and seem normal in number, size, and distribution. It is probable that the circulation in the anterior and middle cerebrals was mainly carried on through the anastomoses of the posterior and middle cerebrals through their temporal branches.

### *Condition of Brain.*

The brain weighed 1080 grammes; the left temporal lobe presented a general shrinking without any alteration in the configuration of the convolutions, which were atrophied mainly at the expense of the grey matter, and were firm and hard, with the arachnoid and pia mater closely adherent. This atrophy is interesting, as atrophy of the right temporal and parietal lobes has been noticed with small internal carotid arteries by Klebs (6).

### *The Dura Mater* (fig. 2).

From the anterior division of the middle meningeal artery a branch of considerable size runs almost directly forwards. This branch, which is a very much enlarged orbital (Quain) or lacrimal (Macalister) branch of the middle meningeal, does duty for the ophthalmic artery on the left side,

but on the right side is an accessory ophthalmic. In accordance with this fact, the orbital branch of the left middle meningeal is nearly double the size of that on the right side. An examination of the base of the skull shows that both these arteries pass through the outer part of the sphenoidal fissure. From the trunk of the middle meningeal on the right side another branch runs forwards and slightly inwards. An examination of the base of the skull shows that this branch is also present on the left side, and that in each case it passes through the foramen rotundum.

*The Base of the Skull.*

The depth of the middle fossa is greater on the right side than on the left, in accordance with the atrophy of the left temporal lobe. There is no carotid canal present in the petrous portion of the temporal bone on either side. The orbital and infra-orbital branches of the middle meningeal, already referred to, produce very deep grooves leading to the outer part of the sphenoidal fissure and to the foramen rotundum respectively. The groove for the orbital artery was not occupied by the ophthalmic division of the fifth, and lay some way to the outer side of the groove for the infra-orbital artery, which, however, was also occupied by the second division of the fifth nerve. An enlarged meningeal branch of the ascending pharyngeal artery enters the skull through a foramen Vesalii on each side, and is distributed to the dura mater of the cavernous sinus. Unfortunately, the orbits were not preserved, and the intra-orbital course and relations of the ophthalmic arteries could not be ascertained.

*The Condition in the Neck.*

The external carotids are considerably enlarged and tortuous, and give off their usual branches, finally dividing at the usual level into superficial temporal and internal maxillary arteries. The ascending pharyngeal and occipital spring from a common stem.

## Developmental Considerations.

Before giving the facts referred to a developmental explanation, it may perhaps not be out of place in this connexion to review shortly a few well-known facts concerning the development of the internal carotid and stapedial arteries. In this it will perhaps be safe to follow closely the very clear account given in the section devoted to the subject in Keibel and Mall's *Embryology* (7), founded on researches by de Vriese, Tandler, and others (fig. 3). The internal carotid consists morphologically of three elements—a root portion derived from the third arch; an intermediate portion derived from the dorsal aorta between the third and first arches; and a distal portion,

which is the continuation of the dorsal end of the first arch towards the developing brain. According to de Vriese and others, in all early embryos the internal carotid artery, after giving off the ophthalmic artery, can be

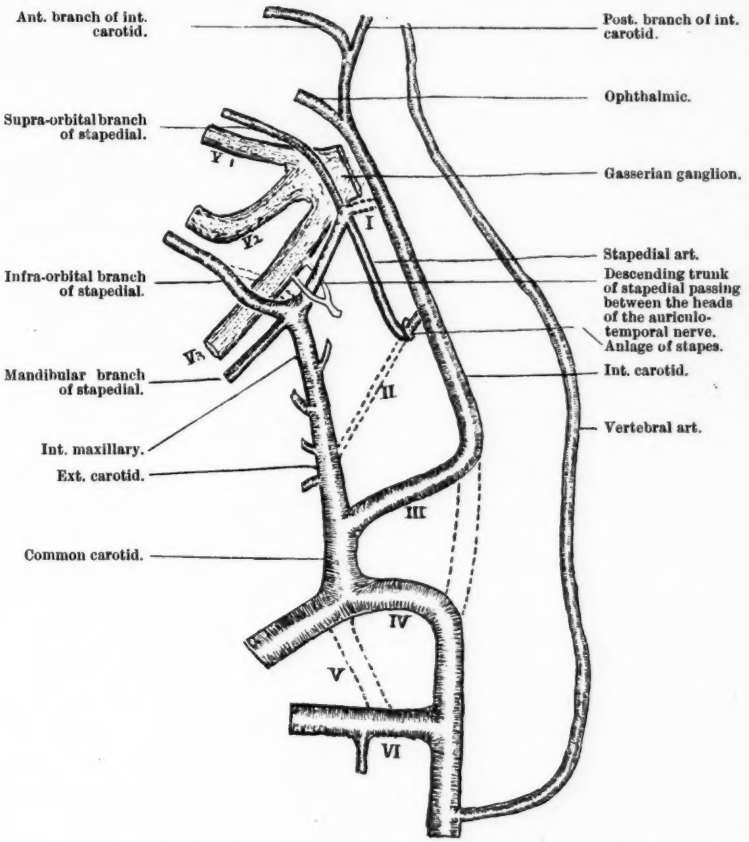


FIG. 3.—Illustrates the development of the internal carotid and stapedial arteries (after Tandler).
I–VI = aortic arches. $V_1$, $V_2$, $V_3$ = divisions of fifth nerve.

seen to divide into an anterior and a posterior branch, of which the latter is by far the more important, and sweeps back to join the cerebral vertebrals. The anterior branch, after giving off the anterior choroidal, runs by the side of the fore-brain, and finally meets its fellow of the opposite side just

behind the nasal pit. This vessel is the anterior cerebral. It gives off in its course a number of branches, which are afterwards concentrated to form the middle cerebral. The posterior cerebral artery is at first represented by a number of branches which come off the posterior terminal branch of the internal carotid. Even in the 48-mm. stage there are present a large artery to the mid-brain and a small true posterior cerebral (Mall). The double posterior cerebral in the case under consideration is thus a retention of the earlier condition. When the two cerebral vertebrals join to form the basilar, the posterior branches of the internal carotid run into this, and the posterior cerebrals appear to spring from the basilar. This appearance is strengthened by the fact that the posterior branch of the internal carotid migrates outwards at a somewhat later stage, and, now known as the posterior communicating, joins the posterior cerebral some little way from the point where the latter joins the basilar artery.

*Stapedial Artery* (fig. 3).

Tandler has shown that the dorsal portion of the second arch becomes the root of the stapedial artery. This vessel persists throughout life in certain animals, *e.g.* the rat, but is said to atrophy in man. When fully developed it possesses, after piercing the anlage of the stapes, three branches —supra-orbital, infra-orbital, and mandibular—which accompany the three divisions of the fifth nerve. The infra-orbital branch at first passes to the inner side of the third division of the fifth to reach the second division of the fifth. The infra-orbital and mandibular branches spring from a common stem, which becomes surrounded by the two roots of the auriculo-temporal nerve. In the 15-mm. embryo the common stem is joined by an anastomosis with the external carotid, this trunk forming the internal maxillary artery. At about the same time the trunk of the stapedial artery is said to atrophy, and therefore transmits its branches to the internal maxillary. The blood now flows in the reverse direction in the descending trunk, which becomes the middle meningeal. The orbital and infra-orbital branches of the middle meningeal, in the case which we have been discussing, are thus seen to be the persisting supra-orbital and infra-orbital branches of the stapedial artery; although, in order to explain why the infra-orbital artery is a branch of the middle meningeal, we must assume that anastomosis took place between external carotid and *mandibular* branch of stapedial.

An examination of the 20-mm. human embryo reveals the interesting fact that the descending trunk of the stapedial is not present at this stage. The stapedial can be seen to course backwards and outwards from its origin from the internal carotid artery to the anlage of the stapes which it per-

forates. It then runs forwards and outwards over Meckel's cartilage and, passing to the outer side of the Gasserian ganglion, gives off an ascending branch which is the middle meningeal artery (fig. 4). Having given off

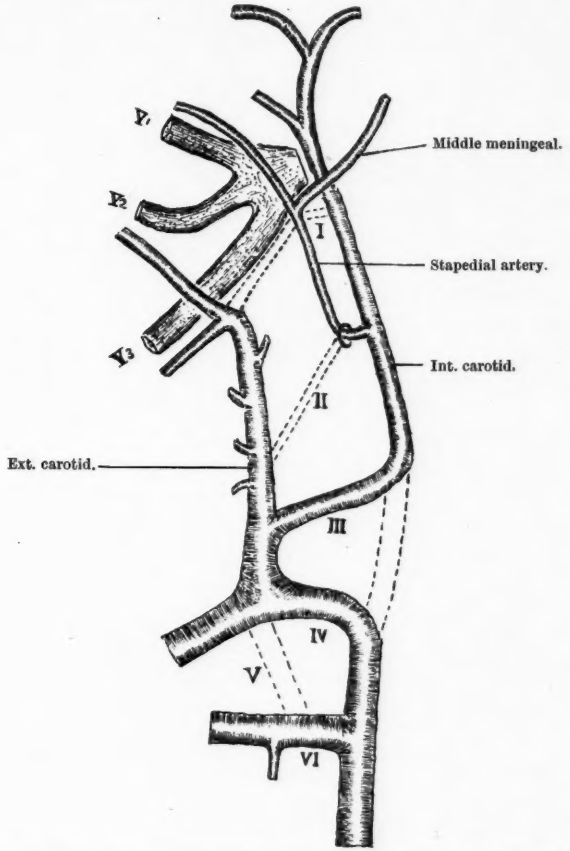


FIG. 4.—From 20 mm. human embryo: origin of middle meningeal artery.

the middle meningeal, the stapedial is then continued on to the orbit. The internal maxillary is seen to give off infra-orbital and mandibular rami. It would seem thus that the intracranial part of the middle meningeal is developed from an ascending branch of the stapedial, and at an earlier stage than the extra-cranial part. Further research may show that this lower

or extra-cranial part is developed at a later stage either by a downgrowth from the stapedial artery to the internal maxillary or by an upgrowth from the internal maxillary to the stapedial.

In the 60-mm. human embryo, an artery corresponding to the stapedial of the earlier stage can be traced without any lack of continuity from the internal carotid to the middle meningeal arteries. At such a stage as this, one may tentatively suggest that the portion of the artery proximal to the stapes is the tympanic branch of the internal carotid, and the portion distal to the stapes is the petrosal branch of the middle meningeal. It is a well-known fact that the petrosal or Fallopian branch of the middle meningeal enters the petrous bone at the hiatus Fallopii and supplies twigs to the tympanic cavity; these anastomose with the tympanic branch of the internal carotid. In young rats which have been specially injected, the stapedial artery is seen to emerge from the hiatus Fallopii and then give off the middle meningeal in addition to its other branches. These observations are of a preliminary nature, and are the subject of further investigation.

To sum up shortly the condition present with regard to the absence of both internal carotids: they in all probability developed, and then at a very early stage, probably at about the 5-mm. period, they began to atrophy, at about the point where they divide into anterior and posterior branches.

Order of process of atrophy:—

(*a*) Continuation forwards of internal carotid distal to first arch.
(*b*) Dorsal aorta between first and second arches.
(*c*) Dorsal aorta between second and third arches.
(*d*) Third arch.

Before concluding, I must express my thanks to Professor Fawcett for his advice and help, and for permitting me to examine embryos from his collection.

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## A CASE OF CONGENITAL ATRESIA OF THE DUODENUM, ACCOMPANIED BY VOLVULUS OF THE ILEUM.

By REGINALD J. GLADSTONE, M.D. Aberd., F.R.C.S. Eng., *Lecturer on and Senior Demonstrator of Anatomy, King's College, London.*

THE early and accurate diagnosis of the condition which has given rise to symptoms of obstruction of the bowel in a newly born child, is of considerable importance with regard to the possibility of relieving the obstruction by operation. Congenital atresia of the duodenum is a fairly

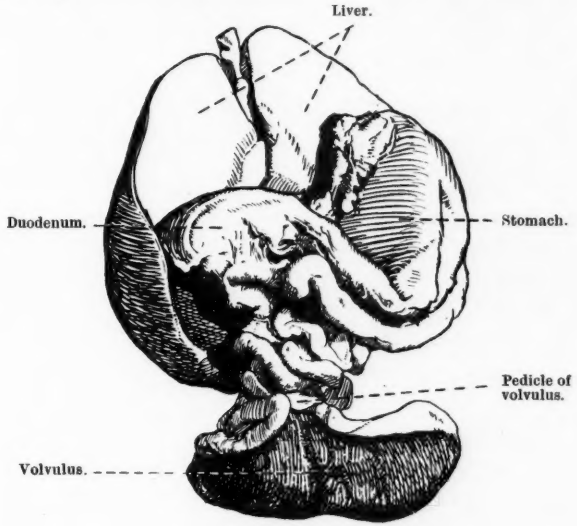


FIG. 1.

common cause of obstruction, and it is thus of interest from the practical as well as from the scientific standpoint.

The specimen which I shall now describe occurred in a male child and was sent to me by Mr W. Maxwell Penny, who kindly furnished me with the following particulars of the case. There was a considerable quantity of liquor amnii, and the child when born appeared small and ill-developed. It soon showed evident signs of obstruction; the condition

of the child, however, did not admit of an operation being performed at the time, and it died on the seventh day after birth.

External examination of the body showed distension of the abdomen, and escape of meconium from the anus. On opening the abdomen, I saw a distended portion of the bowel, of a dark green colour, stretching transversely across the abdominal cavity. This proved to be a volvulus of the ileum 18 cm. above the ileo-cæcal junction, and involving about 10 cm. of the gut. The peritoneum was smooth and glistening, and showed no obvious signs of peritonitis (fig. 1).

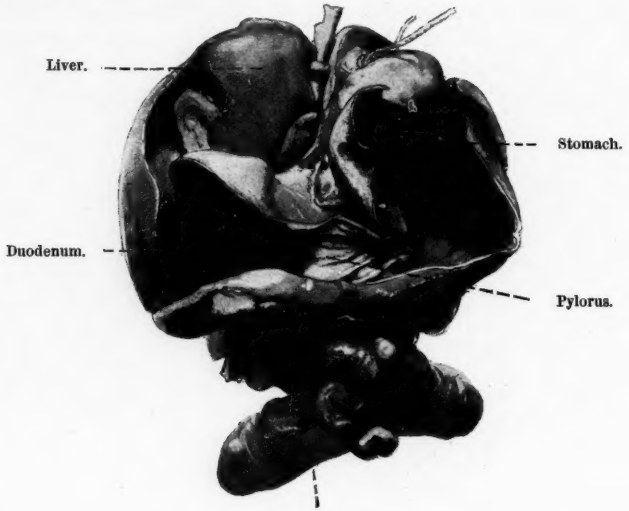


FIG. 2.

On further examination I found the stomach and upper part of the duodenum were also distended, and that there was a complete break in the continuity of the intestine at the junction of the common bile-duct with the duodenum (fig. 3). The duct was connected by a Y-shaped extremity with both segments of the duodenum. On slitting it up I found that the upper limb of the Y-shaped duct, which was connected with the proximal segment of the duodenum, ended blindly, and that the pancreatic duct was connected with the lower limb. The superior mesenteric vessels emerged from beneath the distended upper portion of the duodenum. Fig. 2 shows the stomach and duodenum opened from the front. The pylorus and the relation of the duodenum to the liver and gall-bladder are well seen. No

meconium was present in the stomach, or upper part of the duodenum, but it was present below. The gall-bladder was empty and compressed against the under surface of the liver by the distended portion of the duodenum.

The causation of atresia of the intestine has of late been studied chiefly by Tandler, Kreuter, and Forssner. Tandler in 1892 demonstrated that a proliferation of the epithelial lining of the duodenum takes place in embryos of from thirty to sixty days, and that the lumen thus becomes more or less completely obliterated. In an embryo of 8·5 mm. he recorded

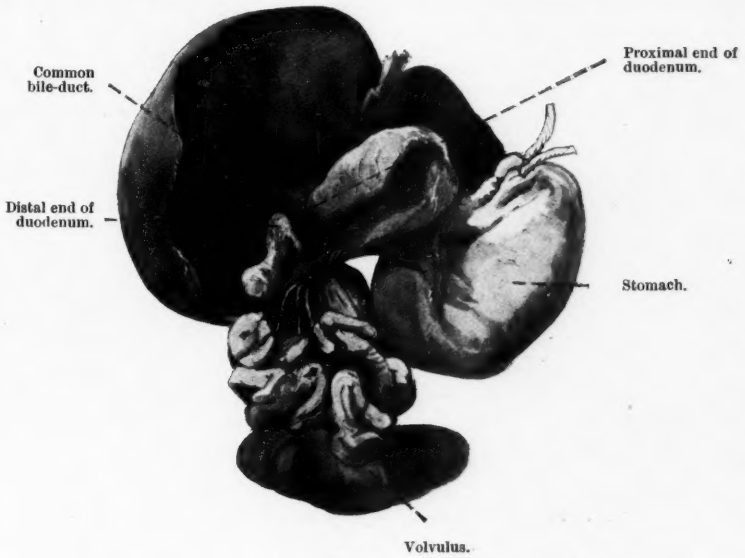


FIG. 3.

a complete obliteration between the outlets of the dorsal pancreas and the common bile-duct. Tandler considered that the cause of the occlusion was the resistance exerted on the expanding epithelium by the surrounding mesenchyme. Since the time when Tandler first put forward the theory that the atresia of the duodenum which occurs in the embryo may sometimes persist up to the time of birth, and cause obstruction, it has been shown that this proliferation of the epithelium may take place in other parts of the intestine, and may even involve a considerable tract of the alimentary canal. Atresia is, however, much more common in the duodenum (one-third of the total number of cases) than in other parts of the small intestine, and it is especially common at the entrance of the common bile- and pancreatic

ducts. It thus appears to me that some external condition may contribute to the obliteration of the intestine, *e.g.* a fibrous remnant of the right vitelline vein in the lower half of the 8-shaped anastomosis round the duodenum. A very few cases are apparently due to fibrous bands, the result of ante-natal peritonitis.

Through the kindness of Professor Waterston I am enabled to show a photograph of a section through the intestine in a 6-mm. human embryo (fig. 4), which illustrates the proliferation of the intestinal epithelium de-

FIG. 4. — Proliferation of epithelium in the small intestine of a 6-mm. human embryo. The dotted line indicates the position of the serous covering of the intestine and its mesentery. From a specimen belonging to Professor D. Waterston.

scribed by Tandler and Forssner. The section passed through the intestine just below the vitello-intestinal junction. The lumen as shown in the photograph appears as a mere speck. The proliferation is also well marked in the duodenal region, but the lumen is here quite distinct.

The cause of the volvulus in the specimen which I have described was probably an irregular peristalsis, set up by the obstruction. An interesting case of intestinal obstruction in a new-born child which was associated with volvulus was described in 1905 by Grosse and le Lorier. The child was delivered at the eighth month. During its expulsion great quantities of greenish amniotic fluid came away. After birth the child vomited much green fluid resembling the liquor amnii in colour,

and the authors considered that the greenish colour of the amniotic fluid might have been due to the vomiting of the child *in utero*. It was noted, however, that meconium passed *per anum*, and the staining of the liquor amnii may be accounted for in this way, without presupposing intra-uterine vomiting of the child. Distension supervened on the fifth day. Le Lorier operated. The stomach and nearly six inches of small intestine were distended, the lower part of the intestinal tract being empty. There was a volvulus of the distended bowel held down by two coils of empty gut. All the signs of general peritonitis were present. A constricting band was divided and an anastomosis established between the two blind ends of the intestine. The child died two hours afterwards. This case was believed to have been one of "intra-uterine tuberculosis of the fœtus," and that the adhesions had developed several weeks before birth and, further, that one of them had completely severed the bowel.

Ante-natal peritonitis will not, however, account for those cases in which a considerable length of the intestine is obliterated, and in which there are no signs of peritonitis. These are obviously due to a congenital defect in development.

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# OBSERVATIONS UPON CASES OF ABSENCE OF LACRIMAL BONES AND OF EXISTENCE OF PERILACRIMAL OSSICLES.

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## Introduction.

This investigation was carried out in the Anatomical Department of the University of Sydney under the direction of Professor J. T. Wilson.

The total number of skulls examined in connexion with the investigation was 391. Of these, only 204 were entire or nearly so on both sides with respect to the lacrimal regions. Of the remainder, 64 were complete on the right side only, and 52 on the left; there was thus a total number of 523 orbits investigated. Those with both sides damaged are not taken into account in the figures given. The skulls were obtained, mostly, from the collections of the Australian Museum, Sydney, and the University of Sydney. Of these, about 42 per cent. were Melanesian, 20 per cent. Australian, 8 per cent. Polynesian, 21 per cent. were not geographically classified at all, whilst the remainder were mixed European. Thus at least more than 70 per cent. are of Oceanic origin (including Australian), which fact probably accounts for the marked disparity between my own figures and those of various other observers who have based their observations on skulls, the great majority of which were European. It is usual to base the percentages upon the total number of skulls examined, whether with orbits broken or not; but, as I have ignored those damaged on both sides, the percentages are shown with respect to the number of skulls having, at least, one orbit intact; thus my figures tend to be higher than those of most other observers. A more satisfactory method would be to base the percentages upon the total number of intact orbits. I have also included in my tables the results of the application of this method.

It is by no means always easy to recognise the presence or otherwise of a supernumerary ossicle and to demonstrate whether such exists quite apart from the surrounding bones; in fact, it is often impossible to do so without complete disarticulation. In fortunate cases an ossicle is quite movable and free in its bed; in other cases, though apparently distinct on the surface, it may be merely a superficial process of an underlying bone. A difficulty, too, is often experienced in recognising sutures, as they need

to be distinguished from post-mortem fractures, and especially lines of absorption so common in old skulls, and which, in some cases, completely circumscribe a portion of the lacrimal. Vascular furrows, such as the lower end of the sutura notha (which was formerly regarded as an articulation), are sometimes deceptive. These usually present the appearance of a channel rather than a mere apposition of two bones, and do not penetrate the whole thickness. In certain very translucent lacrimal bones, the lines of attachment of intercellular septa are apt to be mistaken for sutures.

Hiatuses, which very frequently exist, especially in old skulls, are generally due to absorption from encroachment of the subjacent air-cells, and in such cases are filled up by mucoperiosteum during life. In a few cases a rudimentary lacrimal bone, or perhaps some ossicle, has fallen out. Post-mortem fracture and caries can be recognised, as a rule, by the character of the edges. Lastly, failure of two adjacent bones to meet, as has happened in cases described under superior and inferior lacrimo-ethmoidal ossicles, leaves sometimes a hiatus with perfectly smooth edges and perhaps filled up by membrane during life.

I shall, first of all, submit a summary of the results of this investigation. The details of the investigation of the several conditions dealt with in the summary will occupy the remainder of the paper.

## Summary.

### A. *Absence of Lacrimal Bones.*

I have met with definite complete absence in three cases, or 0·9 per cent. of skulls; once on both sides (native of New Britain), and twice on the left side only (negro and native of New Britain). Of the latter, in one case, the right lacrimal was rudimentary, and in the other, there was a hiatus from which a rudimentary right bone had evidently dropped out. Thus, in every case, the tendency to abolition was present on both sides.

In two other cases I met with hiatuses from which I was unable to be sure whether or not rudimentary lacrimals had dropped out. In a sixth case a hiatus existed on the right and a rudimentary bone on the left side.

### B. *Perilacrimal Ossicles.*

The following are usually described:—

(i.) Superior Lacrimo-ethmoidal . . . }
(ii.) Inferior Lacrimo-ethmoidal . . . } = Retrolacrimal.
(iii.) Lacrimo-ethmoidal . . . . }
(iv.) Ossicle of Lacrimal Groove . . . = Prelacrimal.

(v.) Ossicle of Nasal Canal . . . .
(vi.) Ossicle of Hamulus . . . . } = Infralacrimal.
(vii.) Ossicle of Infraorbital Margin . .

I would add, though it cannot be definitely settled that they exist as quite distinct ossicles, the following species of which I can find no description:—

(viii.) Middle Lacrimo-ethmoidal.
(ix.) Fronto-lacrimal.
(x.) Inferior Maxillo-lacrimal.

Though not strictly perilacrimal, I have also noticed the following as quite distinct ossicles:—

(xi.) Maxillo-frontal (not that of Macalister, which is an ossicle of the lacrimal groove and articulates with lacrimal).
(xii.) Fronto-ethmoidal.

(i.) *Superior Lacrimo-ethmoidal.*—I met with this bone five times, equal to 1·5 per cent. of skulls, being relatively nearly four times as frequent as Thomson found it. He, however, examined a collection of skulls the greater portion of which were broken. My cases were one each from Australia, Melanesia, and Polynesia, and two had not their origins marked; all, like those of Le Double (five in number), were unilateral.

(ii.) *Inferior Lacrimo-ethmoidal.*—I came across this ossicle fifteen times, or in 4·7 per cent. of skulls, being nearly eight times as frequently as Thomson met it. Of these fifteen, five each were from Melanesia and Australia, being 3·6 and 7·9 per cent. respectively of the total skulls of these regions; two from Polynesia, or 8 per cent.; and three were not marked. Thus it appears to be relatively more frequent among Australian and Polynesian skulls; also in Melanesian skulls, though not to the same extent. Of all other skulls (twenty-five of which have the localities marked upon them), there are only three cases of inferior lacrimo-ethmoidal, or 3·1 per cent. None of the three are marked as to their origin, and it is probable that most of the unmarked skulls are Oceanic.

In one case only, that of an Australian, was the presence of this ossicle bilateral; of the others, nine were on the right, and five on the left.

(iii.) *Lacrimo-ethmoidal.*—I saw this ossicle eight times, or in 2·3 per cent. of skulls, being slightly less frequent than Bianchi and Ottolenghi found it, and about eleven times as often as Thomson met with it. Omitting two, the orbits of which were damaged on the opposite sides, only one was bilateral; and of the others, three were on the left and two on the right.

This bone is often described as a part of the os planum (lamina papy-

racea) divided by a vertical fissure. Sometimes, as in one of my cases, the ethmoid is divided into three separate ossicles by two vertical sutures. Similarly, the ethmoid has been described as being divided into four and even five ossicles. When the anterior angles are separated off by oblique sutures, a superior or inferior lacrimo-ethmoidal ossicle is formed.

*Comparison of Post-lacrimal Ossicles.*—In only one instance did I note the coexistence of two different post-lacrimal ossicles in the same skull, viz. a superior lacrimo-ethmoidal on the right, and a lacrimo-ethmoidal on the left. A superior lacrimo-ethmoidal on one side and an inferior lacrimo-ethmoidal on the other are reported. Macalister records on one side superior and inferior lacrimo-ethmoidal, and ossicles of lacrimal groove and nasal canal, and Le Double reports the first two only on one side. Only once I met with inferior lacrimo-ethmoidal on both sides, which, according to Le Double, is very rare.

Excluding the middle lacrimo-ethmoidal, I have found the post-lacrimal ossicles twenty-seven times, equal to 8·4 per cent., whilst Thomson has met with them in only 1·1 per cent. of cases.

Le Double states that the lacrimo-ethmoidal is more common than the superior lacrimo-ethmoidal, and that the latter is more frequent than the inferior lacrimo-ethmoidal, whilst Thomson found just the reverse. I have found the inferior lacrimo-ethmoidal fifteen times, the lacrimo-ethmoidal eight times, and the superior lacrimo-ethmoidal five times.

From observation of so many cases I am of Le Double's opinion that. with few exceptions, the post-lacrimal ossicles are either formed from cartilage in the membranous interval behind the lacrimal, or are developed as dismembered portions of the os planum of the ethmoid. I regard it as improbable that the inferior lacrimo-ethmoidal is formed by irregular clefts running up from the lower border of the ethmoid, cutting off a portion of the latter.

(iv.) *Ossicle of Lacrimal Groove.*—I only met with this ossicle twice (equal to ·6 per cent.); in neither case was the source of the skull indicated. Each was on the right side, and in both cases the opposite sides were not available. With the single exception of Legge, I find it much less frequently than other observers, and it is probably considerably rarer in Oceanic than in European skulls. Of twenty-two cases reported by Luschka, Le Double, Romiti, and Bianchi, fourteen were bilateral, so this condition is apparently more frequent than the unilateral.

(v.) *Ossicle of Nasal Canal.*—I have come across this ossicle fifty-six times, equal to 17·5 per cent., or a little less frequently than other observers. However, it is sufficiently common to be worthy of mention in text-books of osteology.

From an analysis of the varying relations of this ossicle to the vertical, longitudinal, and transverse fissures, when such exist, I have been unable to formulate any definite conclusions as to their connexions with one another, as they are extremely variable.

(vi.) *Ossicle of the Hamulus.*—Altogether I came across this ossicle forty-six times, or in 14·4 per cent. of skulls. Excluding twelve, the orbits of which were damaged on the sides opposite to which the ossicles were present, of the remaining thirty-four, nine were bilateral, eleven on the right and fourteen on the left being more frequently on one than on both sides. As my results show a much higher frequency than those of Macalister, Thomson, and Le Double, I have estimated the frequency of

TABLE I.—TO SHOW NUMBERS, SOURCES, AND CONDITION OF LACRIMAL REGION OF THE SKULLS EXAMINED.

| | No. of Skulls. | Entire on Right and Left. | Entire on Right Side Only. | Entire on Left Side Only. | Total No. of Orbits. |
|---|---|---|---|---|---|
| Africa | 7 | 6 | 1 | ... | 13 |
| Europe | 5 | 3 | 1 | 1 | 8 |
| America | 4 | 1 | 2 | 1 | 5 |
| Asia | 9 | 5 | 1 | 3 | 14 |
| Oceania Australia | 63 | 47 | 11 | 5 | 110 |
| ,, Melanesia | 137 | 82 | 32 | 23 | 219 |
| ,, Indomalaysia | 2 | ... | ... | 2 | 2 |
| ,, Polynesia | 25 | 13 | 6 | 6 | 38 |
| ,, Micronesia | 2 | 1 | ... | 1 | 3 |
| Not marked | 65 | 46 | 10 | 9 | 111 |
| Total | 319 | 204 | 64 | 51 | 523 |

the Oceanic cases in order to compare with those not Oceanic (excluding those whose locality is not stated). Thus it was 16·5 per cent. in the former to only 4 per cent. in the latter, hence I conclude it is very probable that the os hamuli is considerably more frequent in Oceanic than in other skulls.

Though both the ossicle of the canal and the os hamuli in typical cases are easily distinguishable from each other, there are many cases where it is by no means easy to identify them; in fact, one can, through a series of skulls, observe a fairly close gradation from the one type to the other. Such a condition suggests that the two may have a similar mode of development, and I see no reason why the ossicle of the canal, even when it coexists with the os hamuli, should not be developed from the lower

TABLE II.—SHOWING GEOGRAPHICAL SOURCES OF THE NUMERICALLY STRONGER CATEGORIES OF LACRIMAL AND PERILACRIMAL VARIETIES MET WITH IN THE INVESTIGATION.

| Locality. | B (i.) Superior Lacrimo-Ethmoidal. | | | | B (ii.) Inferior Lacrimo-Ethmoidal. | | | | B (iii.) Lacrimo-Ethmoidal. | | | | B (v.) Ossicle of Nasal Canal. | | | | B (vi.) Ossicle of Hamulus. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of Skulls. | No. of Orbits. | Percentage of Skulls. | Percentage of Orbits. | No. of Skulls. | No. of Orbits. | Percentage of Skulls. | Percentage of Orbits. | No. of Skulls. | No. of Orbits. | Percentage of Skulls. | Percentage of Orbits. | No. of Skulls. | No. of Orbits. | Percentage of Skulls. | Percentage of Orbits. | No. of Skulls. | No. of Orbits. | Percentage of Skulls. | Percentage of Orbits. |
| Europe | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 | 1 | 20 | 12·5 | ... | ... | ... | ... |
| America | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 | 1 | 25 | 20 | ... | ... | ... | ... |
| Africa | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Asia | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 | 1 | 11·1 | 7·1 | 1 | 1 | 11·1 | 7·1 |
| Oceania Australia | 1 | 1 | 1·5 | ·9 | 5 | 6 | 7·9 | 5·4 | 2 | 2 | 3·1 | 1·8 | 9 | 11 | 14·2 | 10 | 11 | 13 | 17·7 | 11·8 |
| ,, Melanesia | 1 | 1 | ·7 | ·4 | 5 | 5 | 3·6 | 2·2 | 3 | 3 | 2·1 | 1·3 | 30 | 35 | 21·8 | 16·0 | 22 | 25 | 16·0 | 11·4 |
| ,, Indomalaysia | ... | ... | ... | .. | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| ,, Polynesia | 1 | 1 | 4 | 2·6 | 2 | 2 | 8 | 5·2 | ... | ... | ... | ... | 2 | 2 | 8 | 5·2 | 4 | 5 | 16 | 13·1 |
| ,, Micronesia | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | 1 | 2 | 50 | 66·6 |
| Not marked | 2 | 2 | 3·0 | 1·8 | 3 | 3 | 4·6 | 2·7 | 3 | 4 | 4·6 | 3·6 | 12 | 16 | 18·4 | 14·4 | 7 | 10 | 10·7 | 9·0 |
| Total | 5 | 5 | 1·5 | ·9 | 15 | 16 | 4·7 | 3·0 | 8 | 9 | 2·5 | 1·7 | 56 | 67 | 17·5 | 12·8 | 46 | 56 | 14·4 | 10·7 |
| | Right side . 1<br>Left side . 4 | | | | Right side . 9<br>Left side . 5<br>Bilateral . 1 | | | | Right side . 2<br>Left side . 3<br>Bilateral . 1<br>Excluded because damaged on opposite side . . 2 | | | | Right side . 9<br>Left side . 16<br>Bilateral . 11<br>Excluded because damaged on opposite side . 20 | | | | Right side . 11<br>Left side . 14<br>Bilateral . 9<br>Excluded because damaged on opposite side . 12 | | | |

ADDITIONAL NOTES TO TABLE II., relating to the distribution of skulls manifesting other categories of lacrimal variations omitted from the Table.

A Absence of lacrimal bone. One case Negro ; two Melanesian.
B (iv.) Ossicle of lacrimal groove. Localities unmarked.
B (vii.) Ossicle of infraorbital margin. Nil.
B (viii.) Middle lacrimo-ethmoidal. One case Asiatic ; one Australian aboriginal ; one unmarked.
B (ix.) Fronto-lacrimal. Three cases Australian aboriginal ; one Melanesian.
B (x.) Inferior maxillo-lacrimal. One case from New Britain, the other three unmarked.
B (xi.) Fronto-ethmoidal. Two cases, both Melanesian.
B (xii.) Maxillo-frontal. One case only, Melanesian.

part of the fibrous band which stretches from the anterior to the posterior lacrimal crest in the same way that the os hamuli is.

(vii.) *Ossicle of Infraorbital Margin.*—I did not meet with any indubitable instance of this type.

(viii.) *Middle Lacrimo-ethmoidal.*—Of the three cases, one was in an Asiatic, another in an Australian, and the third was not marked; two were on the right side, and the third on the left side.

(ix.) *Fronto-lacrimal.*—Of the four cases of which I took notes, all were Oceanic, viz. three Australian and one Melanesian. In two cases the ossicle appeared to be derived from the lacrimal, a third from the frontal, while the origin of the fourth was indeterminate.

(x.) *Inferior Maxillo-lacrimal.*—I have notes of four cases, and the only one with the locality marked on it comes from New Britain.

(xi.) *Fronto-ethmoidal.*—I have seen two cases, both right-sided, which were very well marked. The skulls were Melanesian.

(xii.) *Maxillo-frontal.* –The only case I have seen was in a native of Pentecost Island, New Hebrides, where the ossicle existed on both sides. Moreover, it was freely movable and very well marked.

## Discussion of the Various Conditions above Summarised, together with Description of Cases.

### A. *Absence of Lacrimal Bone.*

Like all other bones of the skull, the lacrimal bone tends in later life to fuse with its neighbours, and this occurs by far the most frequently with the nasal process of the maxilla in front. When such happens it progresses from above downwards, so that often the anterior maxillo-lacrimal suture can be recognised below, even when it is obliterated above. In such cases the lacrimal retains its thin papyraceous and often translucent texture, whilst the nasal process remains thick and opaque, and at the site of the obliterated suture there is a sudden change from the one to the other. The anterior lacrimal crest undergoes no change whatever. The part of the lacrimal in the lacrimal groove is very often fenestrated.

Apart from such cases, and often in very young subjects where all other sutures are very distinctly marked, there is no trace of a lacrimal bone whatever, its place being taken generally by the thick nasal process of the maxilla extending beyond the posterior lacrimal crest to articulate with the anterior border of the os planum. In such cases, a suture can usually be made out between the orbital plate and nasal process of the maxilla, and the anterior lacrimal crest is quite rounded. Such absence often occurs on both sides; but in cases where it is unilateral, on the opposite side the

lacrimal is either rudimentary or there exists a hiatus from which possibly a rudimentary lacrimal has fallen out.

The following table represents the frequency as met with by different authors (mostly from Le Double):—

| Author. | No. of Cases. | No. of Skulls. | Percentage of Skulls. |
|---|---|---|---|
| Adachi . . . . . | 6 | 121 | 5 |
| Zabel . . . . . | 3 | 200 | 1·5 |
| Bianir. . . . . | 5 | 350 | 1·4 |
| Macalister . . . . | 2 | 150 | 1·3 |
| Le Double . . . . | 1 | 100 | 1 |
| Flecker . . . . . | 3 | 319 | ·9 |
| Merkel and Kallius . . | 1 | 1000 | ·1 |
| Total . . . . . | 21 | 2240 | ·9 |

Of ten cases reported by Adachi, Le Double, and myself, six were bilateral, three on the left, and one on the right, so that absence occurs apparently more frequently on both sides than on one side only.

Whether the absence is due to actual non-appearance of the centre of ossification or to the centre being crushed out by or fused with the more actively growing nasal process of the maxilla, it is difficult to ascertain; but considering the frequency of abortive bones on the sides opposite to those on which the lacrimal bones are absent, the latter seems the more probable.

In my three cases the missing lacrimals were replaced mainly by the nasal process of the maxilla together with a small part of either the orbital plate of the maxilla or of the os planum. Le Double describes three other types of replacement of the absent bone. The suture between the orbital and nasal processes of the maxilla occupies the usual position of the inferior maxillo-lacrimal suture, when the hamulus is ill-developed.

### Description of Cases.

Case 1, A 18956, *Australian Museum.*

Native of Blanche Bay, New Britain. Replaced on each side by nasal processes of maxilla only.

Case 2, 296, *Anatomy Department, University of Sydney.*

Adult male negro. Sutures fairly distinct. Lacrimal replaced on left entirely by thick process of maxilla articulating with thin os planum behind posterior lacrimal crest. On right side lacrimal is rudimentary.

Case 3, S 310, *Australian Museum, Sydney.*

Skull from Gazelle Peninsula, New Britain. Replaced entirely on left by nasal process of maxilla extending behind posterior lacrimal crest. On right is hiatus, from which rudimentary bone has evidently dropped out.

Case 4, A 18966, *Australian Museum, Sydney.*

Native of Rapanui, Easter Islands. Hiatus in front of ethmoid on both sides, from which it is difficult to determine whether a rudimentary bone has not dropped out.

Case 5, S 1055, *Australian Museum, Sydney.*

Native of Ontong, Java. Hiatus on right in front of ethmoid; on left are two others, where, possibly, rudimentary bones have dropped out.

Case 6, 2, *Anatomy Department, University of Sydney.*

Female, adolescent, from Chatham Isles. Sutures very distinct. Replaced on right side mainly by thick nasal process of maxilla and thin descending process of os planum. Between the two is a hiatus, from which a very rudimentary bone has evidently dropped out. On the left side the lacrimal is rudimentary.

### B. *The Perilacrimal Ossicles.*

(i.) *The Superior Lacrimo-ethmoidal* is a small triangular ossicle with its base upward, articulating with the frontal above, the lacrimal in front, and the ethmoid behind.

*Ossification.*—The lacrimal bone is formed in membrane covering the ethmoid cartilage externally. The date for the appearance of the first centre, as stated by different observers, varies from as late as the fifth month to as early as the eighth week. Macalister, in ten embryos of eight weeks, found it nine times on both sides, once on the left, but never found it in a younger specimen. Only once did he find it missing in an older specimen (nine weeks).

At the end of the fifth month the lacrimal part, usually pierced by numerous foramina, is entirely ossified; it is separated from the os planum by a membranous interval. Ossification extends forward to the anterior border, and behind to the posterior lacrimal crest, which is recognisable by the twelfth week, and then extends behind the lacrimal crest to meet the os planum. At eight months all the sutures are well formed, except the lacrimo-ethmoidal, in the upper two-thirds of which cartilage is still visible. It is from this cartilage that the superior lacrimo-ethmoidal ossicle is developed. It therefore resembles the ethmoid, and differs from the lacrimal in being developed from cartilage and not directly from membrane.

Macalister states that normally there is only one centre of ossification for the lacrimal, and that supernumerary ossicles usually are developed from separate abnormal centres. Macalister, too, describes the superior lacrimo-ethmoidal ossicle as being a dismemberment of the ethmoid. Apparently he makes no distinction between this ossicle and the lacrimo-ethmoidal, and he regards the latter as an enlarged superior lacrimo-ethmoidal separating the lacrimal from the ethmoid.

### Description of Cases.

Case 1, *Anatomy Department, University of Sydney.*

Youth, locality not stated. Canine teeth not yet erupted. Sutures very distinct. Ossicle on right triangular; base 2 mm., articulates with frontal; anterior border 3 mm., articulates with os planum. The bone appears very distinctly to be a part of os planum. On left side ethmoid divided into three pieces by two vertical sutures. (Case 2, Lacrimo-ethmoid.)

Case 2, 26, *Macleay Museum, University of Sydney.*

Female skull, locality not marked. Form of equilateral triangle with sides 4 mm. On left side.

Case 3, 1173, *Australian Museum, Sydney.*

Native of New South Wales. Ossicle takes form of equilateral triangle with sides 4 mm. On left side.

Case 4, 2159, *Anatomical Museum, University of Sydney.*

Adult skull from Acid River, New Guinea. Sutures fairly well marked. Ossicle is on left side; approximates form of equilateral triangle, with sides measuring about 4 mm. Lower angle rounded.

Case 5, S 994, *Australian Museum, Sydney.*

Juvenile from North Island, New Zealand. On right, along the greater part of fronto-ethmoidal suture, is a long hiatus about an inch in length, and from 2 to 4 mm. wide. It is probably due to failure of union of frontal with ethmoid. Its boundaries are quite smooth, and probably the gap was filled up by membrane during life. The ossicle present is L-shaped (inverted), with one limb ($8 \times 2$ mm.) wedged in between lacrimal and ethmoidal, and the other ($6 \times 2$ mm.) bounding the anterior part of the hiatus above.

(ii.) *The Inferior Lacrimo-ethmoidal* is a small triangular ossicle with its base downward, articulating with the orbital plate of the maxilla, and its anterior and posterior edges with the lacrimal and os planum respectively. Though typically triangular, it varies a great deal in form and size from a very small circle to a large square or rectangle. In two cases it was duplicated on the same side.

Macalister states that this ossicle is not usually ethmoidal in origin, but that it is a part of the infraorbital plate of the maxilla, which is irregularly cleft in this region. Though I have noticed the frequency of these clefts and also of an ascending process of the orbital plate of the maxilla, such an origin seems to me very improbable. Moreover, these clefts are usually more or less parallel, and do not tend to run into each other at all; and even if they did meet, the base of the triangle would not be a straight line or nearly so, as is usually the case.

In at least two cases I have seen the ossicle surmounting an ascending process of the maxilla which is itself irregularly cleft, but not in such a way as to form another ossicle. It appears to me that the inferior lacrimo-ethmoidal, like the lacrimo-ethmoidal and superior lacrimo-ethmoidal, is formed in the membranous interval behind the lacrimal, and may be regarded as a disjointed part of the ethmoid.

In cases where the ossicle articulates with the frontal above, resembling a lacrimo-ethmoidal as in two of my cases, the ossicle is situated on an ascending process of the orbital plate of the maxilla. In one case the frontal articulated with the orbital plate of the maxilla, separating the ossicle from the ethmoid.

### Description of Cases.

Case 1, B 10390, *Australian Museum, Sydney.*

Native of Queensland. On left is square ossicle, with sides 4 mm., apparently derived from ethmoid. On right are two triangular ossicles, the upper being the larger, with sides measuring 6, 6, and 3 mm., and the sides of the lower being 3, 3, and 2 mm.

Case 2, 762, *Anatomical Museum, University of Sydney.*

Skull of an anencephalic fœtus, measuring about $7\frac{1}{2}$ cm. from posterior border of foramen to symphysis menti. A small triangular gap exists between adjacent angles of maxilla, ethmoid, and lacrimal, filled in by membrane, each side measuring 4 mm., closest to maxilla, and 2 mm. from os planum. It seems that ossicle is derived either from an entirely distinct centre or from the orbital plate of the maxilla.

Case 3, 1232, *Australian Museum, Sydney.*

Native of Wide Bay, Queensland. A youth aged about fourteen. On left is a somewhat large triangular ossicle with anterior and posterior borders 8 mm., and base 6 mm. Apparently derived from ethmoid, like the lacrimo-ethmoidal ossicle. Same skull as Case 4, Fronto-lacrimal.

Case 4, B 7065, *Australian Museum, Sydney.*

Old native of Cobar, New South Wales. Anterior lacrimo-maxillary suture synostosed. Small triangular ossicle, with longer sides 4 mm., and base 1 mm.

Case 5, A 18953, *Australian Museum, Sydney.*

Old native of Easter Isles. Tiny circular ossicle, 1 mm. in diameter, surmounting ascending process of maxilla.

Case 6, S 1052, *Australian Museum, Sydney.*

Adult native of New Caledonia. On left is a small circular ossicle measuring 3 mm. in diameter. Sutures are well marked.

Case 7, A 14330, *Australian Museum, Sydney.*

Native of Arorai Island, Gilbert Group. Two small circular ossicles in apposition on left side, measuring 1 and 2 mm. in diameter respectively. They surmount a slight ascending process of the maxilla.

Case 8, S 321, *Australian Museum, Sydney.*

Native of New Britain. On left side is large quadrangular ossicle 10 × 4 mm., with long axis antero-posterior. Hiatus in upper part of lacrimo-ethmoidal suture. Apparently detached part of lacrimal. Upper border of lacrimal fused to frontal bone.

Case 9, Sie. XIII. 1651, *Macleay Museum, University of Sydney.*

Native of Cape York, Queensland. Sutures quite distinct. Large square ossicle, with sides 6 mm. on right, surmounting an ascending process of maxilla and separating the lacrimal from the ethmoid, thus simulating a lacrimo-ethmoidal ossicle.

Case 10, S 300, *Australian Museum, Sydney.*

Adult skull from New Guinea. Sutures well marked. Ossicle situated on the left on an ascending process of maxilla. It articulates above with the frontal, separating the lacrimal from the ethmoid, thus simulating lacrimo-ethmoidal. Ossicle is somewhat quadrilateral, measuring 2 × 3 mm. In front it articulates with the posterior superior angle of the lacrimal bone by a point only. On the right side the ascending process of maxilla just meets the descending process of the frontal bone.

Case 11, S 318, *Australian Museum, Sydney.*

Native of Gazelle Peninsula, New Britain. Large square ossicle, with sides 5 mm.; the upper and posterior borders articulate with the ethmoid, of which the ossicle appears to be a detached part.

Case 12, 15, *Macleay Museum, University of Sydney.*

Locality not marked. On the right is a long lacrimo-ethmoidal 1 × 6 mm., separated from the ethmoid by a large descending process of the frontal articulating with a still larger ascending process of the maxilla along a line running obliquely from before, downwards and backwards.

Case 13, D, *Anatomical Museum, University of Sydney.*

Adult skull from Solomon Islands, with tendency of sutures to fuse. On right side are two absorption foramina in the ethmoid, also a hiatus due to absorption between the adjacent upper borders of lacrimal and ethmoid. There is a very small inferior lacrimo-ethmoidal, roughly

circular, with diameter 2 mm., surmounted by hiatus about 4 mm. long; the ossicle surmounts a slight ascending process of the orbital plate of maxilla, and appears to be formed as detached part of os planum.

Case 14, 1230, *Australian Museum, Sydney.*

On the left is a large, long ossicle, 10 × 4 mm., with long axis vertical. A large hiatus, 15 × 4 mm., exists between the maxilla and ethmoid. The ossicle does not reach the hiatus, which extends into the middle meatus of the nose, and, like that described as Case 5, Superior Lacrimo-ethmoidal, its margins are quite smooth.

Case 15, 4, *Anatomical Department, University of Sydney.*

Male aboriginal of Australia. Ethmoid synostosed to all surrounding bones except lacrimal. Pulley of superior oblique ossified. Small circular ossicle in notch of ethmoid, with diameter 2 mm.

(iii.) *Lacrimo-ethmoidal.*—This is generally a comparatively large ossicle, square or oblong in shape, and wedged in between the lacrimal and os planum in front and behind, and the frontal and maxilla above and below.

The following table represents the frequency as met with by different observers:—

| Author. | No. of Cases. | No. of Skulls. | Percentage of Skulls. |
|---|---|---|---|
| Bianchi . . . . | 9 | 286 | 3·1 |
| Flecker . . . . | 8 | 319 | 2·5 |
| Ottolenghi . . . . | 6 | 265 | 2·3 |
| Thomson . . . . | 2 | 1037 | ·2 |
| Total . . . . | 25 | 1907 | 1·3 |

In most instances this ossicle appears to be part of the ethmoid separated off by a vertical fissure. Macalister figures it as an enlarged superior lacrimo-ethmoidal. In one case I found it separated from the ethmoid by the meeting of an ascending process of the maxilla with a descending process of the frontal.

Altogether I have noted this union of process of the frontal and maxilla behind the lacrimal in ten different skulls. Two were broken in the opposite orbit; of the remainder, four were bilateral, three on the right and one on the left side only. In one case this union occurred behind the lacrimo-ethmoidal, in another in front of the same ossicle, and in two others behind the inferior lacrimo-ethmoidal.

Thomson expresses the view that perhaps the superior and inferior

lacrimo-ethmoidal may fuse with the frontal and maxilla respectively, giving rise to the appearance of union of ascending and descending processes of these two bones behind the lacrimal. Owing to the rarity of the co-existence of these two ossicles, compared to the frequency of union of such processes, I believe such an explanation unlikely.

### Description of Cases.

Case 1, 18, *Macleay Museum, University of Sydney.*

Male skull, locality not stated. On both sides are quadrilateral ossicles measuring 6 × 3 mm.; on left divided into two by horizontal suture.

Case 2, *Anatomy Department, University of Sydney.*

Same skull as Case 1, Superior Lacrimo-ethmoidal. Ethmoid divided into three by two vertical sutures cutting off two quadrilateral ossicles in front, each measuring about 5 × 2 mm. surmounting a slight ascending process of maxilla.

Case 3, S 317, *Australian Museum, Sydney.*

Native of New Britain. Youth aged about fourteen. Well-marked ossicle on right side measuring 8 × 6 mm. with long axis vertical. Apparently part of ethmoid. Small gap exists between ossicle and maxilla.

Case 4, 20, *Anatomy Department, University of Sydney.*

Hog Harbour, New Hebrides. Quadrilateral ossicle with long axis vertical, measuring 8 × 4 mm. Apparently either is developed as a separate bone altogether or from the ethmoid.

Case 5, 20, *Macleay Museum, University of Sydney.*

Female skull, locality not stated. Large square ethmo-lacrimal, with sides measuring 6 mm. Is on left side.

Case 6, 493, *Anatomical Museum, University of Sydney.*

Skull of young Australian male aboriginal. Sutures very distinct. Ossicle roughly quadrilateral; upper border 5 mm., posterior 5 mm., lower 4 mm., sloping forward and upward, surmounting ascending process of maxilla, and anterior 2 mm. sloping downward and backward.

Case 7, S 3513, *Australian Museum, Sydney.*

Native youth of Mallicollo Island, New Hebrides, artificially distorted; wisdom teeth not yet fully erupted. On left side ossicle directed obliquely downward and forward. Ethmoid considerably higher than lacrimal, probably due to the distortion. Upper border of ossicle directed also obliquely downward and forward, measuring 12 mm., anterior border 4 mm., lower 8 mm., posterior 10 mm. Apparently is detached part of os planum.

Case 8, A 5114, *Australian Museum, Sydney.*

Adult native of Point Darwin, Northern Territory. Oval-shaped ossicle with long axis vertical; axes measuring 5 and 3 mm. respectively. Separated from lacrimal by articulation of maxilla and frontal behind the lacrimal.

(iv.) "The Ossicle of the Lacrimal Groove" (Le Double); "Nebenthränenbein" (Luschka); "L'osso accessorio della fossa lacrimale" (Taruffi); "Maxillo-frontal" (Macalister).

This is usually a quadrilateral ossicle, articulating with the frontal above, the lacrimal behind, and the maxilla in front and below. It presents a lacrimal and a facial surface separated by the anterior lacrimal crest. According to Luschka it lies very loosely attached in its bed. Luschka notes also that the facial part is not usually present, which statement is contrary to what Le Double describes. One of my cases had a facial surface, the other had not. One was firmly united, the other very loosely attached in its bed.

The following table represents the frequency noted by different writers:—

| Author. | No. of Cases. | No. of Skulls. | Percentage of Skulls. |
|---|---|---|---|
| Luschka | 7 | 60 | 11·6 |
| Canestrini and Woschen | 2 | 34 | 5·8 |
| Le Double | 4 | 100 | 4 |
| Budge | 6 | 184 | 3·2 |
| Krause | 3 | 100 | 3 |
| Romiti | 1 | 40 | 2·5 |
| Bianchi | 10 | 425 | 2·3 |
| Macalister | 10 | 1020 | ·9 |
| Flecker | 2 | 319 | ·6 |
| Legge | 3 | 760 | ·3 |
| Total | 48 | 3042 | 1·5 |

The sutura notha grooving the nasal process of the maxilla should not be mistaken for an articulating suture. It is produced by a small branch of the infraorbital artery grooving the bone; it is quite superficial and does not penetrate the entire thickness of the nasal process. Usually it can be traced from the lower margin of the orifice of the nasal canal upwards, and it is very constant.

### Description of Cases.

Case 1, 45, *Macleay Museum, University of Sydney.*

Juvenile skull, sutures very distinct. On the right is a thin, right-angled triangular squame, with sides measuring 4, 4, and 6 mm. respectively, overlying nasal process of maxilla; base articulates behind with anterior border of lacrimal near its upper extremity; the hypotenuse looks upwards and forwards, and the third side looks downwards. Is perfectly free in its bed. The anterior angle just reaches the anterior lacrimal crest.

CASE 2, *Skull in own possession.*

Ossicle roughly oblong, 4 × 2 mm. Articulates behind with maxilla and frontal, above with frontal, and below with part of nasal process of maxilla in the lacrimal groove. All these sutures are distinctly marked. The anterior, however, is not quite so evident, owing to its squamous edge overlapping the facial part of maxilla. The anterior lacrimal crest is continued up the centre of the ossicle. Same skull as Case 1, Inferior Maxillo-lacrimal.

In a broken skull, belonging to a student, which I am now unable to obtain, I saw the ossicles on both sides, articulating in front with the nasal bones, differing from those usually described. The anterior lacrimal crests are continued up over the ossicles.

(v.) *Ossicle of the Nasal Canal.*—This is a small ossicle situated at the lower margin of the lacrimal. Rousseau describes four surfaces—a free external or orbital, lying as a rule, below the hamulus and above the orbital plate of the maxilla; a second surface forms with the lacrimal bone, the outer and upper part of the nasal canal; a supramaxillary articulates below with the orbital plate of the maxilla; and the fourth is usually overlain by the hamulus, with which it generally coexists. When the hamulus is ill developed, this surface forms part of the upper margin of the nasal canal.

Among the 319 skulls I have met this ossicle fifty-six times, equal to 17·5 per cent. Other observers find it in the following proportions:—

| | | |
|---|---|---|
| Gruber | in the majority of cases. | |
| Rousseau | in from 50 to 60 | per cent. |
| Macalister | traces in 55 | „ |
| „ | distinct in 32 | „ |
| Bianchi | in 25 | „ |
| Krause | in 20 | „ |

According to Le Double, the ossicle corresponds to the commencement of the vertical infraorbital fissure, and to the part of the maxilla in front and above the transverse infraorbital.

The sutura verticalis is that running upward from the infraorbital or accessory infraorbital canal; while the sutura longitudinalis is that stretching from the most posterior part of the root of the infraorbital canal forwards. Both show a very great variation in direction. Both may run almost parallel to each other outward until they become covered by the molar; both may run almost parallel to each other inward towards the inner margin of the orbital plate of the maxilla, while every intermediate stage can be found. Most frequently the sutures run inward. They may run towards each other and meet, when frequently a third suture (sutura

transversa) runs inwards towards the lacrimal. The meeting of the suturæ longitudinalis and verticalis may be anywhere from under cover of the malar to the inner edge of the orbital plate of the maxilla, while very frequently they do not meet at all.

Of the sixty-seven orbits in which I found the ossicle of the canal, in thirty-nine these sutures were either absent or unrecognisable in the proximity of the ossicle of the canal. Of the remaining twenty-eight, in ten cases both the suturæ longitudinalis and verticalis ran to the ossicle without uniting; in two cases the sutura transversa was formed running towards the same; in eleven cases the sutura verticalis, and in one only the sutura longitudinalis ran to the ossicle of the canal. Those cases where the sutures do not run to the ossicle are included in the first thirty-nine. From these figures almost every possible relation of these sutures to the ossicle is present, and I can find no evidence of any definite or constant connexion of the one to the other.

Macalister states "When the hamulus exists the ossicle is excluded from the lacrimal canal by it, and I have never found it (ossicle of canal) stretching beneath the hamulus so as to come into the wall of the tube." Nevertheless, I have frequently found an ossicle of the canal, under cover of the hamulus, so loose that on gently pressing the external surface of the ossicle, the internal surface protrudes in very definite relief in the lachrymal canal.

Instances of this type are too numerous to be worthy of individual description.

(vi.) *Ossicle of the Hamulus.*—This is an ossicle sometimes met with at the upper margin of the opening of the lacrimal canal, and it usually coexists with an ill-developed hamulus. It represents, according to Macalister, a separate centre of ossification arising in a constant fibrous band stretching between the lower ends of the anterior and posterior lacrimal crests. Though I met with this ossicle in 14·4 per cent. of skulls, Le Double only found it in 2 per cent., whilst Macalister and Thomson each found it in $1\frac{1}{2}$ per cent.

As distinctive points between the ossicles of the canal and hamulus it is stated that—

(1) The former lies on the maxilla and indents it, not the lacrimal, as does the latter.

(2) The ossicle of the canal usually coexists with a well-developed hamulus in the majority of cases, whilst the os hamuli generally is present with an ill-developed hamulus. Macalister records a case where the ossicle of the canal completely separated the lacrimal from the orbital plate of the maxilla.

Though the above characteristics are quite sufficient for recognition of the majority of cases, there still remain a few cases in which the decision must be arbitrary, as I find almost every degree of variation between the two types. The first-mentioned distinction, I believe, is only a matter of degree as where two bones come into contact with each other, one generally must leave at least a slight impression upon the other. The difficult cases to identify are those in which, with an ill-developed hamulus, an ossicle is met with at the upper margin of the nasal canal, then the distinction between the two must be purely arbitrary.

Of the sixty-seven cases of ossicle of the canal, in fifty-two was it completely under cover of the hamulus; in eight it was only partially so, and in seven the hamulus was not sufficiently well developed to be over it. In such cases as the latter the continuation of the curve of the lower end of the posterior lacrimal crest would usually pass quite above the ossicle, and would not be continuous with its upper border as in the case of the os hamuli when such exists.

In many cases the two ossicles coexist in the same orbit. Their recognition, then, is a matter of no difficulty, as the upper one is always the os hamuli.

Instances of this type are too numerous to be worthy of individual description.

(vii.) *Ossicle of the Infraorbital Margin.*—I did not meet with any indubitable instances of this type.

(viii.) *Middle Lacrimo-ethmoidal.*—In several cases I have met with small ossicles in the lacrimo-ethmoidal suture about half-way between its upper and lower extremities. Though fairly well marked in one case, the others are not sufficiently definite to be recognised absolutely as a distinct ossicle. However, as they cannot be classed with the other post-lacrimal ossicles, I would propose to label it "Middle Lacrimo-ethmoidal." It is probably developed in the same way as the other ossicles in front of the os planum.

### Description of Cases.

Case 1, 39, *Macleay Museum, University of Sydney.*

Locality not stated. On the left side is a circular ossicle, 2 mm. in diameter at the junction of lower quarter and upper three-quarter of the lacrimo-ethmoidal suture. Is quite free superficially.

Case 2, 1184, *Australian Museum, Sydney.*

Skull of Mongol. Many of the sutures are obliterated. There is a small oval ossicle with axes 4 and 1½ mm., long axis vertical at junction of lower third and upper two-thirds of lacrimo-ethmoidal suture.

Case 3, 1157, *Australian Museum, Sydney.*

Female aboriginal, New South Wales. On right side, near the middle of lacrimo-ethmoidal suture, is an ossicle measuring 2 × 4 mm. with long axis vertical, evidently part of ethmoid. Probably has a deep connexion with ethmoidal, but is quite free superficially. Same skull as Case 2, Fronto-lacrimal.

1142, *Anatomical Museum, University of Sydney.*

In a fourth skull, where the sutures were particularly well marked, was the appearance of a triangular ossicle with its sides measuring 8, 6, and 4 mm. fused with the ethmoid for a very slight extent below and behind. It was on the left side, a little below the middle of the lacrimo-ethmoidal suture.

(ix.) *Fronto-lacrimal.*—Though ossicles are not usually described in the fronto-lachrymal suture, I have made notes of four cases. I have been unable to find any definite evidence as to the mode of development of these ossicles, whether from the frontal or from the lacrimal, but considering the high frequency of irregular processes extending from the frontal, perhaps it may be part of that bone. Three of the cases at least could not be so isolated as to be demonstrated absolutely as a distinct ossicle.

Description of Cases.

Case 1, Sic. xiii. 1652, *Macleay Museum, University of Sydney.*

Native of Cape York, Queensland. On left side is a long narrow ossicle measuring 8 × 1½ mm. in the lacrimo-frontal suture, apparently quite distinct from either the frontal or the lacrimal. Sutures are quite well marked.

Case 2, 1157, *Australian Museum, Sydney.*

Same skull as Case 3, Middle Lacrimo-ethmoidal. The ossicle measures 3 × 2 mm., and possibly has a deep connexion with the lacrimal.

Case 3, 38, *Macleay Museum, University of Sydney.*

Native of Mabiac Island, Torres Straits. Ossicle measures 3 × 2 mm., and probably has a deep connexion with the frontal.

Case 4, 1232, *Australian Museum, Sydney.*

Same skull as Case 2, Inferior Lacrimo-ethmoidal. On the right side is a small circular ossicle measuring 2 mm. in diameter at the junction of the posterior third and the anterior two-thirds of the fronto-lacrimal suture. Is probably a part of the lacrimal.

(x.) *Inferior Maxillo-lacrimal.*—In several cases I have seen ossicles situated along the inferior maxillo-lacrimal suture behind the line of the hamulus, and behind the usual situation of the ossicle of the canal. Such an ossicle is not usually described, but as it may possibly be of a different

nature from the ossicle of the canal, I have given it the name of the suture in which it lies. It has the appearance of the ossicle of the canal placed a little further back than usual, but it does not, as far as I can ascertain, take any part in the formation of the lacrimal canal.

Description of Cases.

Case 1, *Skull in own possession.*

Same skull as Case 2, Ossicle of Lacrimal Groove. Ossicle is somewhat quadrangular, measuring 3 × 1 mm., with long axis antero-posterior. The hamulus is well developed. The ossicle lies behind the coronal plane of the posterior lacrimal crest, and appears to take no part in the formation of the lacrimal canal. Though the ossicle indents the lacrimal and not the maxilla, very likely, like the ossicle of the canal, it is a part of the latter and is probably developed in the same way.

Case 2, 34, *Macleay Museum, University of Sydney.*

In left orbit is an oval ossicle measuring 3 × 1½ mm., 3 mm. distant from the lower end of the lacrimo-ethmoidal suture.

Case 3, 39, *Macleay Museum, University of Sydney.*

On right side is a tiny ossicle measuring 2 × 1 mm. in the right maxillo-lacrimal suture, and it is probably a part of the inferior turbinal.

Case 4, 530, *Australian Museum, Sydney.*

Native of New Britain. On the right side, between the adjacent borders of the lacrimal and ethmoid, is a hiatus. In the posterior part of the inferior maxillo-lacrimal suture is a long squamous ossicle, wedged in between the lacrimal and orbital plate of the maxilla. It measures about 8 × 1 mm.

(xi.) *Fronto-ethmoidal.*—In two cases I have met with ossicles running across the fronto-ethmoidal suture. They are most definitely marked. One was in a Fijian native, and the locality of the other was not stated.

Description of Cases.

Case 1, 1194, *Australian Museum, Sydney.*

Locality of skull not marked. A well-defined square ossicle, with sides measuring 3 mm. exists in the fronto-ethmoidal suture, about 4 mm. from the posterior superior angle of the lacrimal.

Case 2, *Macleay Museum, University of Sydney.*

Native of Fiji. Sutures very distinct. Distinct fronto-ethmoidal ossicle measuring 4 × 3 mm. behind the upper end of the lacrimo-ethmoidal suture.

(xii.) This is an ossicle which I have met with in only one case in the suture between the nasal process of the maxilla and the frontal bone. It

differs from the ossicle of the lacrimal groove (maxillo-frontal of Macalister) in not articulating with the lacrimal. It is a particularly well-defined specimen.

ONLY CASE, A 14326, *Australian Museum, Sydney.*

Native of Pentecost Island, New Hebrides. On right side is a small ossicle measuring 2 × 3 mm. in the fronto-maxillar suture, midway between the lacrimal and nasal bones. On the left side, in the same suture but nearer the lacrimal bone, is a similar freely movable ossicle which is slightly larger.

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## SOME POINTS IN THE NOMENCLATURE OF THE EXTERNAL GENITALIA OF THE FEMALE.

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The present communication is intended as an introduction to a study of the development and morphology of some of the cloacal derivatives of the mammalia.

Some such preliminary survey is necessary, since there is so great a lack of definition concerning some of the terms in common use that the correct comparison of similar parts in different forms becomes difficult, and detailed description often well nigh meaningless. I imagine that this state of affairs arises directly from the extraordinary wealth of names which has accumulated in the literature of the female genito-urinary orifices. It is only necessary to turn to the authors of the seventeenth century to appreciate what a multitude of names had then been bestowed as general terms for the whole external genitalia. Thomas Gibson (1688), after giving a long list of classical and popular terms for the pudendum, says that it is known by all these "and many other names that fancy has imposed upon it." One of these more popular terms is worthy of some note. In describing the pudendum, Helkiah Crooke (1651) gives many synonyms, but puts them all aside with the brief sentence: "We will call it the lap"; and with this name he heads his chapter.

It is surely a rare transition for a word, when once so used, to acquire a more polite significance with the passage of time—the change of usage being commonly in the opposite direction. Such a use of the word, however, makes the term "dew lap" more easy of understanding, for I imagine that the definition of the dew lap as "the flesh that hangs from the throat of oxen, which laps or licks the dew on grazing" (Ogilvie), does not represent its true significance, and that a parallel may possibly be found in "dew claw."

Among the many synonyms used by the older anatomists, note must be made of "vulva," "fossa navicularis s. scaphoides," and "vestibulum." All these terms have been used to signify the whole of the external genitalia of the female, comprising that depression which lies between the two labia majora (labio scrotal folds, outer genital folds, labia externa, labia magna pudendi, alæ, alæ magnæ, etc.). A great deal of interest, and much confusion,

is attached to the word vulva or volva. Its original use was without doubt restricted to the womb, and though in lay usage it was commonly confined to the uterus of lower animals, it became the orthodox term for the uterus of women, and as such it is used by Galen and others. At a later period the term became applied to the external genitalia, but if this transition came about by a mere extension of meaning, or by way of the word valva, —the folding doors or flood-gates,—does not seem quite clear (on this point see Bartholin and Crooke).

Be this as it may, the word vulva, although having least claims to do so, has been alone retained in modern literature as the accepted term for the external genitalia of the female; and, since this word has monopolised such a meaning, successive generations of anatomists have been at great pains to delimit parts of the vulva to which other words, originally denoting the whole of the pudendal cleft, could be applied.

Fossa navicularis and vestibulum are the two terms which have been most commonly retained in descriptive anatomy. Both are terms which have lost their original significance, and consequently there is much uncertainty, even to-day, as to the exact parts of the genitalia to which either is properly applied. It is correct to say that in the text-books which are in everyday use among students of anatomy and gynecology these terms bear variable meanings.

Fossa navicularis s. scaphoides was used by the older anatomists (see Th. Bartholin) as a descriptive term for the whole vulva, because the depression between the two labia majora is shaped somewhat after the fashion of a boat; and it should be noted that in its original use the long axis of the imaginary boat is in the long axis of the pudendal cleft.

This use of the word survived for long, and still remains current; for instance, Dr F. H. Ramsbotham states that the fossa navicularis "contains within its precincts the clitoris with its prepuce, the nymphæ, the vestibule, and the meatus urinarius" (p. 40). See fig. 1.

The almost exclusive employment of the word vulva as the scientific term for the pudendal cleft caused a modification in the use of the term fossa navicularis; and it was restricted to the posterior part of the cleft (James Keill), or with more precision to that part of the cleft where the labia minora fall short posteriorly. In more modern usage its significance has become still more limited, but still it is far from precise. According to different authorities the term fossa navicularis may denote:—

(1) The space between the hymen, or the orifice of the vagina, and the bond which is supposed to unite the labia minora posteriorly (Luschka and others). See fig. 2.

(2) The space between the hymen, or the orifice of the vagina, and the

bond which is supposed to unite the labia majora posteriorly (Winslow, Sappey, Broca, and others). See fig. 3.

(3) The space between the hymen, or the orifice of the vagina, and the "fourchette," such fourchette being a derivative of neither labia majora or labia minora (Farre and many gynecologists).

(4) The space between the bond which is supposed to unite the labia majora and the bond which is supposed to unite the labia minora, which bond may or may not be called a fourchette (John Lizars, etc.).

(5) The space between the bond which is supposed to unite the labia majora and a fourchette which is not derived from the labia minora (Gray and others). See fig. 4.

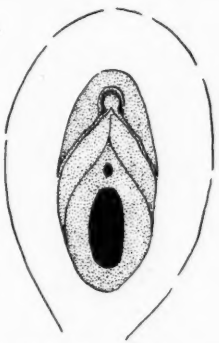

FIG. 1.—The fossa navicularis (stippled area). The area as defined by most early anatomists (Bartholin, etc.) and partially by many modern gynecologists (Ramsbotham, etc.).

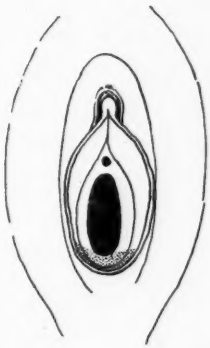

FIG. 2.—The fossa navicularis (stippled area). The area as defined by most gynecologists and many anatomists (Luschka, etc.).

(6) By a strange variant (I know not if by mere printer's error) as the space in front of the vagina limited anteriorly by a fourchette and posteriorly by the orifice of the vagina (Robert Knox).

It should be noted that in all these different delimitations the fossa navicularis is so disposed that the long axis of the imaginary boat is at right angles to the long axis of the pudendal cleft.

A like change has taken place with regard to the word vestibulum. First meaning the outer court into which the chambers of the bladder and the uterus both opened, its use has become steadily more restricted and confused. In its original and correct sense it was in common use with anatomists and gynecologists: "the vestibulum or fossa navicularis is a smooth depression between the nymphæ and perineum; it leads to the

urethra above and the vagina below" (Archibald Robinson). Such a use of the word is retained in the latest edition of Morris's *Anatomy*, but, of course, it is not there a synonym for the fossa navicularis. See fig. 5.

With the restriction of the term fossa navicularis to the hinder part of the pudendal cleft, the vestibulum became the recognised term for the anterior part, and such is its accepted use to-day; but even now the term is ill defined. By different authorities the word vestibulum is stated to denote:—

(1) The triangular space between the labia minora extending as far back as the margin of the orifice of the vagina (Gray, Farre, and others). See fig. 6.

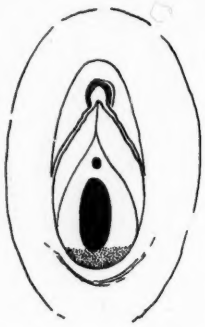

FIG. 3.—The fossa navicularis (stippled area). The area as defined by Winslow, Sappey, Broca, Monro, Cloquet, and many other anatomists.

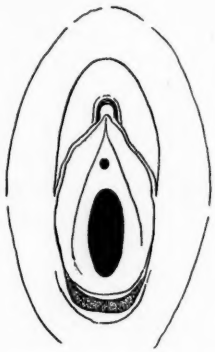

FIG. 4.—The fossa navicularis (stippled area). Area in which the anterior boundary is the "fourchette," which may or may not be derived from the labia minora (Gray and others).

(2) The triangular space between the labia minora extending as far back as the urinary orifice or a line drawn through the centre of this orifice (Sappey, Lewers, etc.). See fig. 7.

(3) A still more limited area which stretches from below the clitoris to the entrance of the urethra. This definition is found most usually in works on gynecology, and such a vestibulum might well correspond to the "bride masculine du vestibule" of Pozzi, or the "habenulæ urethrales" of Waldeyer.

Considerably more difficulty is experienced when we attempt to define exactly what is meant by the fourchette, for this word appears to be one that is surrounded by uncertainty. Its use may be summarised as follows:—

(1) The term fourchette may signify a posterior junction of the labia

majora: *i.e.* it may be a synonym for the commissura inferna of Bartholin, the inferior commissure of Winslow, the posterior commissure of many authors, the frenulum labiorum of Verheyen, or the frenulum pudendi of Cunningham (*Practical*, Ed. 2). See fig. 8.

(2) It may signify a posterior junction of the labia minora and so be a synonym of the frenulum vulvæ of Luschka, or the frenulum labiorum pudendi of Cunningham (*Practical*, Ed. 5). See fig. 9.

(3) It may signify a fold unconnected with either of these, derived from the anterior edge of the perineum (Robert Knox and others); or

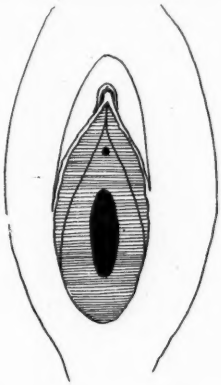

FIG. 5. — The vestibulum (shaded area) as defined by earlier anatomists, adopted by many gynecologists, and retained by some anatomists (Archibald Robinson, Alfred von Behr, Morris, etc.).

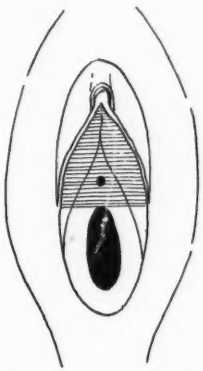

FIG. 6. — The vestibulum (shaded area) as defined by many gynecologists and anatomists (Farre, Gray, etc.).

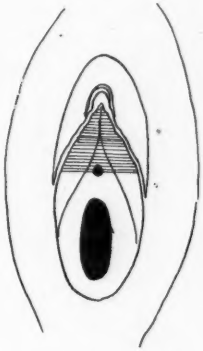

FIG. 7.—The vestibulum (shaded area) as defined by many gynecologists and anatomists (Lewers, Sappey, etc.).

(4) A fold further within the pudendal cleft, but still not a direct derivative of either of the genital folds (Farre and many gynecologists). As such it has been named the "fourchette," "the fork" (Keill, 1703), "the skinny ligament" (Crooke, 1651), or "frenulum pudendi" (Gray, 1882). See fig. 10.

The actual constituent of the external genitalia from which the fourchette is derived and with which it is anatomically continuous is therefore a matter of considerable uncertainty.

The uncertainty is increased by an attitude frequently manifested by authorities on gynecology, that to a certain extent the demonstration of the fourchette and fossa navicularis is a matter of manipulation during

examination. This idea finds free expression in the works of many authors. "The fossa navicularis only assumes the form of a boat-shaped depression when it is stretched laterally by an index finger placed in it on each side" (Galabin, p. 5).

"The fossa navicularis is first formed, and gets its boat shape, when they (labia majora) are separated from each other. On stretching them from side to side we see the posterior commissure advance until it reaches the level of the posterior border of the entrance of the vagina. Thus a fold

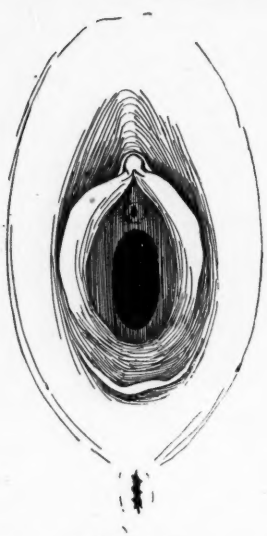

FIG. 8.—The fourchette. Type I. in which the labia majora meet to form a free edge, the labia minora falling short posteriorly.

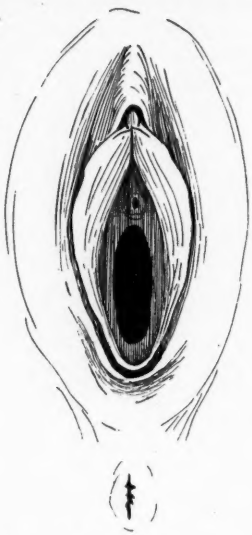

FIG. 9.—The fourchette. Type II. in which the labia minora meet to form a free edge; the labia majora may or may not form a junction at a posterior commissure.

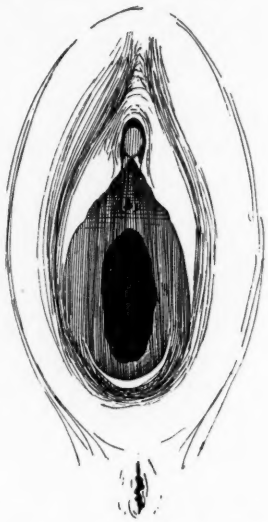

FIG. 10.—The fourchette. Type III. in which the free edge is derived from neither labium.

and a hollow are formed. The fold is the fourchette: the hollow is the fossa navicularis" (Garrigues, p. 40). I think that although such expressions would seem to make the issue more confused, they are in reality the clues for understanding the true nature of the fourchette: especially so when taken in conjunction with a further statement of the last author that, "in virgins the fourchette projects a little forward, even without stretching."

It would seem that concerning the fourchette there is only one point of agreement among all authors, and that is that at the posterior limit of the

pudendal cleft there is a projecting margin which is more or less pronounced in the virgin, but which loses much of its prominence in women who are not virgins, and commonly disappears altogether after the birth of the first child.

According to Bartholin, "inferior commissura labiorum in virginibus tensa est"; or to Crooke, "in those that have brought forth the skinny ligament is much more lax and loose."

What, then, is the anatomical structure which produces this sharp posterior edge of the virgin pudendal cleft?

According to many modern authors it is the backward extension of the labia minora around the vaginal orifice.

Now it must be admitted that the degree of development of the labia minora varies enormously; but I am convinced that for them to be prolonged so far back as to meet behind the vagina is a somewhat unusual event even in the fœtus. A consideration of the true morphology of these folds does not warrant the conclusion that, even in an abbreviated form, it should be their normal condition to meet behind the vaginal orifice. Indeed, it is a comparatively recent innovation into anatomical description that makes such a meeting normal. That they extend backwards "reaching about half the breadth of the orifice of the vagina" (Gibson) is a common description of the older anatomists, which is still retained in some modern text-books (Morris), and which applies to the virgin and non-virgin condition. In a very large proportion of female fœtuses it is quite obvious that although the labia minora fall short about half-way down the vaginal orifice, there is yet a sharp margin at the back of the pudendal cleft. In some cases, it is true, there is an apparent continuation of the line of the labia minora further back than the mid-point of the vaginal orifice, and in some there is an apparent meeting of their backward continuation at the posterior margin of the cleft; but this condition I do not think is the normal one, and it is one that is certainly accentuated by manipulation.

Just as the older anatomists were definite about the failure of the labia minora to meet posteriorly, so many authors are definite about the failure of the labia majora to meet in a posterior commissure or fourchette. "Inferiorly the labia majora do not meet or run together, but terminate apart in front of the perineum" (Robert Knox, p. 508).

Concerning the labia majora, there is ample reason for suggesting that they do not end by becoming united behind the vaginal orifice in front of the anus. It is, I think, merely the unnatural position, and the straining open of the pudendal cleft on examination which makes such a meeting apparent. In the natural position of the parts, with the thighs approximated, the skin ridges which compose the labia majora run straight

backwards and fail by becoming of diminishing prominence at a variable distance on the perineum towards the anus.

If, then, neither labia minora nor labia majora normally meet behind the pudendal cleft at a median bond of union, what other anatomical structure may form the basis of the fourchette?

In the *London Dissector* (J. Scratchley), which reached its eighth edition in 1832, the student was taught that "the perineum anterius projects forwards forming a kind of valve" (p. 89), and such appears to me to be the proper statement of the facts. It is the anterior margin of the "perineum," free of either genital fold, that forms the fourchette, and the disappearance of the fourchette after the first labour represents the minimum—and normal—rupture of the "perineum" accompanying normal labour. The definition of this "perineum" I reserve for a future paper.

There is one other point concerning which there is some difference of opinion shown in text-book descriptions and text-book illustrations, and that is the anterior origin or point of union of the labia minora. To appreciate the true morphology of these structures it cannot be made too definite that they arise as free folds upon the under surface of the clitoris, and not from the preputium of the clitoris with which their apparent continuity is only secondary.

The labia minora start upon the under surface of the clitoris and end upon the sides of the vaginal orifice: the labia majora run as prominent margins along the whole length of the pudendal cleft, but fade away before and behind by becoming merged with the general skin surface. Such, I think, should be the description of the normal disposition of these ridges.

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# A NOTE ON THE SIGNIFICANCE OF CERTAIN ANOMALIES OF THE RENAL AND SPERMATIC ARTERIES.

By J. S. B. Stopford, M.B., Ch.B., *Senior Demonstrator of Anatomy, University of Manchester.*

A RENAL abnormality in a male subject that was recently dissected in the Anatomy Department of the Manchester University appears worthy of record, partly on account of its apparent rarity and partly on account of its developmental interest.

The anomaly is an apparently slight deviation from the normal condition, but it throws an interesting light on problems that are now being discussed from other points of view.

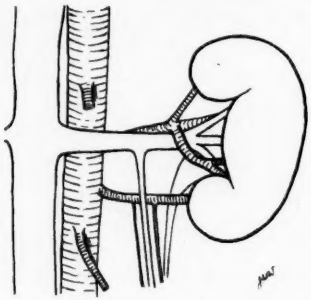
The left kidney, which was normal in size, was situated at a slightly lower level than the right, and its principal artery, arising from the aorta three-quarters of an inch below the superior mesenteric, at the same level as the right renal artery, passed laterally and, before reaching the hilum, divided into three primary branches. The upper one pierced the inner border of the kidney immediately above the hilum; the middle one, after breaking up into several secondary branches, passed into the hilum behind the pelvis of the ureter; and the lower one extended obliquely downwards and laterally across the renal vein to enter the lower part of the hilum.

An accessory renal artery, only slightly less in diameter than the principal one, was present on this side. This vessel took origin from the left side of the aorta, midway between the origin of the renal and inferior mesenteric arteries, and passed laterally in front of the ureteric pelvis to pierce the inner border of the kidney below the hilum. Two spermatic arteries were found arising from this accessory vessel. They passed downwards from their origin at the medial and lateral sides respectively of the point where the left spermatic vein crossed the artery. The lateral spermatic artery was the larger and was comparable in size to the right spermatic artery, a branch of the aorta leaving this trunk at the root of the right renal artery. No aortic spermatic artery could be found on the left side.

There was an additional point, which, although not quite so apparent, was of considerable interest both on embryological and morphological grounds. On the left side the posterior labium of the hilum extended

much further medially than the anterior, *i.e.* the hilum was semi-anterior. On the right side the normal condition was found, the anterior labium extending nearer to the middle line.

Irregularities of the renal arteries are exceedingly common, occurring, according to Thane (1), as frequently as in 25 per cent., and the commonest is the presence of an additional vessel which occurs in about 20 per cent.; whilst according to Macalister (2) irregularities are found as commonly as three times in every seven bodies. The latter observer found that the commonest illustration of plurality of vessels was one right accessory aortic branch, and the next most frequent irregularity was one left accessory aortic branch. Arthur Thomson (3), in the "Report of the Committee of Collective Investigation appointed by the Anatomical Society of Great Britain and Ireland," states that irregularities were found in 25·6 per



cent., and in 10·9 per cent. the irregularity consisted of one accessory aortic branch; this estimate was made from the examination of 419 bodies.

The above evidence is sufficient to show that one accessory aortic renal vessel occurs so very frequently that it can hardly be considered abnormal. Many have suggested that an accessory vessel, occurring below the regular renal artery, may be an important factor in the production of many cases of hydronephrosis; but it is difficult to believe that such a vessel could mechanically obstruct the ureter unless the kidney was unduly movable.

Attention has frequently been drawn by Tyrie (4), Young and Peter Thompson (5), and many others, to the association of abnormal renal vessels with a developmental arrest of the kidney, which is demonstrated either by its shape or position. The ventral position of the hilum is distinctive of many of these cases and has given rise to a good deal of discussion.

Irregularities of the spermatic artery, on the other hand, do not appear to be so common, and I have been unable to discover any account of this vessel arising from an accessory renal artery. The occurrence of a

spermatic artery springing from the renal proper is a recognised abnormality, but there seems to be considerable discrepancy about its frequency. Poirier (6) states that it is rare to see it arising from the renal (especially on the right side). Thane (1) describes it as frequent, and quotes a case of three spermatic arteries occurring on one side—two being aortic and one renal in origin. Robinson and Young (7), Walsham (8), and most English and American text-books mention this variation of the spermatic artery, but do not refer to its frequency, and none apparently describes a case where this artery is a branch of an accessory renal vessel.

An accessory renal artery arising from the spermatic is not very uncommon, but I consider this case to be an illustration of two spermatic arteries springing from an accessory renal: primarily, from the direction of the main trunk as it passes laterally towards the kidney from the aorta; and secondarily (although the second criterion is notoriously misleading), from the size of the branch passing on to the kidney—there being no obvious diminution in calibre beyond the origin of the spermatic vessels. I call attention to this minute distinction for the moment, as this case hardly corresponds to the accepted description of an accessory renal artery arising from the spermatic, although, as I shall endeavour to point out later, the explanation of the anomaly in both cases is probably identical. I also emphasise this distinction between the two, at first sight, identical cases for reasons which become more apparent later.

Explanations of the multiplication of the renal arteries are not difficult to find, as the facts of both comparative anatomy and embryology at once suggest solutions. In the lower animals the renal arteries are multiple, and in birds the ovarian artery is normally a branch of the renal. Also, ever since 1880 it has been known, from the researches of His, that the aortic branches supplying the intermediate cell mass are multiple. Recently Broman (9) has shown that, at any rate primarily, these vessels are arranged segmentally. Nevertheless, the history of these vessels is not yet complete, and explanations of abnormalities in the vessels supplying the structures formed from the intermediate cell mass must remain, as Evans (10) states, speculative until our knowledge of their development is increased.

Hitherto two principal theories have been advanced:—

(1) The "splitting" of the normal renal artery. This theory now receives scanty support, as it hardly appears likely that the vessels should revert to their early condition after attaining the adult state; and recent research discredits this suggested explanation more and more.

(2) Robinson and Young (7) offered an explanation which is best expressed in their own words: "The occurrence of two spermatic arteries

is probably an indication that the testicle was developed in at least two segments of the body; and the origin of a spermatic artery from the renal or suprarenal arteries is due to the obliteration of the root of the original vessel and the enlargement of an anastomosis between intermediate visceral arteries of adjacent segments."

The latter view obviously requires considerable modification in the light of the results of Broman's work; and I offer the following as an explanation, more in accordance with recent research, of the irregularities in the arteries supplying the structures formed from the intermediate cell mass.

In 1911 Jeidell (11) confirmed the supposition that the embryonic kidney was supplied by small capillaries from the neighbouring arteries (such as the inferior mesenteric, middle sacral, etc.), so that the explanation of the abnormal renal arteries illustrated by the cases described by Young and Peter Thompson (5) and Tyrie (4) is now complete. As the kidney passes upwards, it is supplied by the mesonephric (intermediate) or lateral aortic arteries, which atrophy in turn from below as it ascends until—as Hill (12) has demonstrated (by the Schultze method of making translucent specimens)—only the normal renal artery remains by the time the kidney attains its usual adult position.

Since the arteries supplying the intermediate cell mass have been shown to be so numerous as to be segmental, each may supply branches to the tissue forming the genital gland, kidney, and adrenal cortex respectively.

Such branches have frequently been seen by several observers. Yet only four of these intermediate arteries remain in the adult—inferior phrenic, suprarenal, renal, and spermatic (or ovarian). Therefore I suggest that in the process of development of the renal arteries, the branches passing to the genital gland usually atrophy, that vessel being chosen to become the permanent renal which supplies most of its branches to the metanephros. Similarly the vessel of supply to the genital gland is chosen, and normally the branches passing from it to the other glands atrophy.

The frequent presence of an inferior suprarenal branch from the renal and the triple arterial supply to the suprarenal gland are quite in accordance with what one would expect from a consideration of the comparative size of this organ during intra-uterine life and even at birth, and its immobility during development.

The non-disappearance of branches to the genital gland from the principal or accessory renal artery will result in the irregular origin of the spermatic artery mentioned in this paper.

In a similar way accessory vessels to the genital gland may be explained, and all the abnormalities which are so frequent in this region; and I suggest, as corroborative evidence in support of this explanation, a

brief reference to the arteries of the suprarenal gland. In this case the text-books describe an inferior suprarenal passing to the gland from the renal; if my hypothesis holds good, this is a persistence of the embryonic arrangement of the vessels which, as a rule, is not seen in the case of the testicle or ovary. This coincides with what one would expect, as at birth the suprarenal gland is as large as, or larger than, the kidney, and consequently may be described as attaining its relative size late.

Further, the testicle, owing first to its descent, and secondly to the ascent of the kidney, is soon separated from the latter organ, and one would not in consequence expect an illustration of the embryonic condition so frequently.

In conclusion, I beg to express my gratitude to Professor Elliot Smith for permission to publish these notes.

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## A SWEDENBORG MYSTERY: THE RIVAL SKULLS.

By W. RUTHERFORD.

A MYSTERY that is more than curious has arisen with regard to the remains of the great scientist, theologian, and mystic, Emanuel Swedenborg, to whom Emerson devoted one of his best-known essays, and who has been, and is still, held to be one of the most extraordinary men of his age.

In the spring of the year 1908 the Swedish Government despatched a frigate to England to bear away the bones of their great thinker for burial in his native soil. They had been lying for 136 years in the vault of an obscure little Swedish church in an East London slum—Princes Square, St George's-in-the-East—and for generations had attracted very little or no attention. In fact, in the year 1817, as the church books show, the skull was abstracted from the old coffin. The same books state that two years later (in 1819) the skull was replaced: and here begins the mystery.

Half a century ago a collector of curios in Wellclose Square, close to the old Swedish church, exhibited to his friends a skull which he claimed to be that of Emanuel Swedenborg. That collector is dead years ago, but, before passing away, he handed his collection to a friend, who has kept it ever since, but was not aware that this particular skull was amongst the others. None of them were labelled, and it is only now that there has been discovered scratched into the bone of one the letters "E. S'borg."

The discoverer claims for this that it is the actual skull of Swedenborg taken from his coffin in 1817, the probability being that another skull was put into the coffin in 1819 to cover the theft.

In the meantime this alien skull has gone to Sweden and been buried with much pomp and ceremony at Upsala.

Moreover, Swedish anatomists have examined it, one professor has published a treatise upon it, and a bust has been built upon the lines of it. But the mystery still stands, which is the authentic skull—that at Upsala or the one left behind in England? There are few so remarkable at the Royal College of Surgeons, which possesses a museum of thousands. The forehead of the one in England certainly has a similarity in formation to that of the portraits of Swedenborg, and other evidences point to the probability that the discoverer is right. At the same time, no blame attaches to the Swedish men of science. They had to deal with the bones

put before them, and could scarcely be expected to suspect that those bones had been tampered with in England. Then again, human skulls are, as a rule, so very similar in form that it is exceedingly easy to accept one for another, except to the eye trained in such matters.

It is not unlikely that much controversy may arise over this mystery,

FIG. 1.—Norma verticalis.

FIG. 2.—Norma lateralis.

FIG. 3.—Norma occipitalis.

FIG. 4.—Norma facialis.

and it is hard to say what the end will be. Singular indeed is it that the great mystic should be mysterious still, more than a century after death.

*Note.*—The question of the authenticity of the skull ought to be easily settled if there be any data available as to the shape of his head. The photographs show that it is a well-marked example of the not uncommon anomaly of scaphocephalus, due to interparietal synostosis. The condition is obtrusively noticeable during life, and could not escape observation in the

case of any man of public mark. The author of the paper has sent me much literature on the subject, mostly from newspapers, but I have not gathered from it that anyone had, during Swedenborg's life, recognised that he had a scaphocephalic cranium. The figures of the skull are worth reproducing, as they are not only characteristic of this deformation, but they show this unusual feature, that the bregmatic part of the sagittal suture persists for a short distance, a condition which only exists in one of the nine scaphocephalic crania in the Cambridge Museum. There is absolutely no evidence that this cranial deformity is accompanied with any specific type of mental or moral development. The two whom I have known during life were essentially commonplace persons.—A. M.

# EXTROVERSION OF THE BLADDER, COMPLICATED BY THE PRESENCE OF INTESTINAL OPENINGS ON THE SURFACE OF THE EXTROVERTED AREA.

By T. B. JOHNSTON, M.B., Ch.B., *Lecturer on Anatomy, Edinburgh University.*

NUMEROUS methods of classification have been suggested for cases of extroversion of the bladder and its kindred anomalies. The case recorded in this paper falls into the third group of Keith's (1) classification, which is characterised by "ectopia vesicæ combined with fistulous condition of the intestine." A large number of similar cases have been recorded, and Wood Jones (2) has recently described the gross anatomy in detail. On this account the following description is purposely brief.

The child was born at the seventh month and lived for three days. At the time of birth a competent and reliable nurse failed to notice anything unusual about the placenta or membranes, and no membranous bag was attached to the margins of the extroverted area, such as is suggested by Wood Jones (2).

*Gross Anatomy.*—The umbilical cord was normal in appearance, and lay entirely cephalad to the extroverted area. It was median in position, and was situated 8 cm. from the xiphi-sternal junction and 7·5 cm. from the tip of the coccyx. Only the right umbilical artery was present.

The extroverted area showed, as usual in these cases, a median and right and left lateral subdivisions. The small intestine opened in the middle line (fig. 1), 3 cm. caudad to the umbilicus, and about 2·5 cm. more caudally there was a button-like elevation which could be readily invaginated to form a short blind diverticulum (fig. 2). At the caudad edge of this diverticulum there was a slit-like opening leading into the large intestine, which did not open in the perineum, although a distinct proctodœal depression was present.

On the right lateral subdivision there were two openings (fig. 1), which communicated with the right ureter and vagina respectively; no similar openings were found on the left lateral area.

At the caudal end of the extroverted area, in the middle line, there was a small tag-like elevation which resembled a small clitoris.

The stomach and liver were normal, but rotation of the intestines round the axis of the superior mesenteric artery, which normally is present in a

9·4 mm. embryo, had either been incomplete or had not taken place. This was evidenced by the fact that the superior mesenteric artery lay behind the third part of the duodenum, whereas in the ordinary course of development the gut is carried behind the vessel during the process of rotation. The small intestine measured 30 inches from the pylorus to the point where it opened on the surface. The large intestine passed backwards and downwards into the pelvis for 3 cm., and ended blindly. It was supplied upon its posterior surface by the inferior mesenteric artery.

No paired appendices were found in connexion with the large intestine,

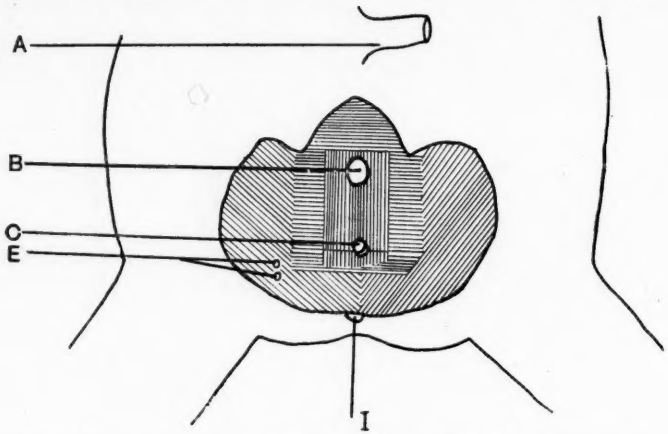


FIG. 1.—Diagrammatic representation of surface view of the case of extroversion described in the text.

A, umbilical cord; B, orifice of small intestine; C, small blind diverticulum, with orifice of large intestine at its left lower margin; E, orifices of right ureter and vagina; I, clitoris. *Note.*—Areas shaded obliquely were covered by mucous membrane of bladder: areas shaded vertically were covered by intestinal mucous membrane: areas shaded horizontally showed transitional appearances.

although these have been described as being constantly present in these cases.

The right kidney lay in the pelvis, but the left kidney was normal in position. The left ureter was enormously distended, and ended blindly in the wall of the left vagina.

The genital organs were female in character. The uteri were quite separate, and the vaginæ were only connected by an impervious fibromuscular bridge at their lower ends. So far as could be discovered, the left vagina did not open on the surface.

Spina bifida, a feature which has been described as constant in these cases, was not present.

*Microscopic Appearances.*—The histology of extroversion of the bladder and its allied conditions is by no means complete. Shattock (3), von Enderlen (4), and Keith (1) have all contributed to the subject, but their work deals mainly with the uncomplicated variety of extroversion of the bladder. In the case recorded in the present paper, most of the extroverted area was subjected to microscopical examination, and the results are given in some detail.

(*a*) The umbilical cord, close to the body, was perfectly normal, except

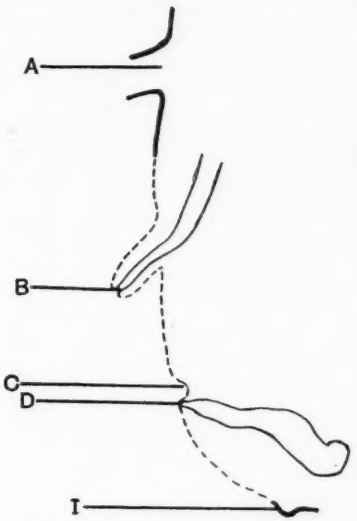


FIG. 2.—Median sagittal section through the caudad part of the anterior abdominal wall of the fœtus described in the text. (Diagrammatic.)

A, umbilical cord; B, orifice of small intestine, prolapsed; C, small blind diverticulum; D, orifice of large intestine; I, clitoris. *Note.*—The extroverted area is represented by a dotted line.

that it contained only one umbilical artery. It was surrounded by a layer of flattened epithelial cells, which constituted a complete amniotic covering. No trace of the urachus was observed, and no remains of the exocœlom were found.

(*b*) Small intestine, caudal end. Typical villi covered the surface, and the submucous and muscular coats were well developed. Very little lymphoid tissue was present in the submucosa, and it was difficult to determine, by the microscopical appearances alone, whether the part examined was jejunum or ileum. The length of the gut from the pylorus to the surface

opening was 30 inches, and, as the child was born at the seventh month, it is practically certain that the caudal portion represented the ileum.

(*c*) The area cephalad to the opening of the small intestine, but caudad to the umbilicus (fig. 1), was covered, at its cephalad end, by stratified epithelium. True skin papillæ were found in places (fig. 3), but not throughout the area. The underlying substance consisted almost entirely of connective-tissue fibres. Where the papillæ were absent, the appearance of the surface epithelium and the underlying tissue supported the view that it represented skin in a slightly modified form.

Sections from the most caudad part of the area, *i.e.* close to the orifice

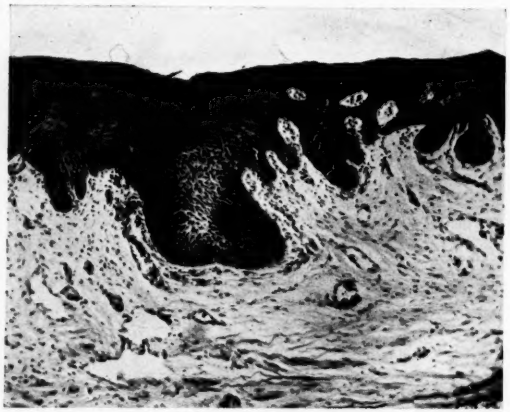

FIG. 3.—Transverse section through area immediately caudad to umbilicus, showing several true skin papillæ.

of the small intestine, showed the typical appearance of mucous membrane of small intestine.

The intermediate part of the area, which should have shown the transition between the two types, was not sectioned at the same time, and, unfortunately, was not in such a good state of preservation when cut at a later date. It was not possible to be certain whether it showed a direct transition from intestinal mucous membrane to skin, or whether there existed an intermediate portion which represented mucous membrane of bladder. The appearances found were suggestive of the latter condition, but, until some further histological evidence is forthcoming, the exact nature of the transition must remain doubtful.

(*d*) The area in the middle line between the two intestinal orifices was cut sagittally. In its cephalad part, the mucous membrane had been par-

tially rubbed off, but it showed the bases of intestinal villi, and the glands of small intestine, lined by secreting cells. In its caudal part, the surface epithelium was well preserved. Typical villi covered the surface (fig. 4), and the number of mucus-secreting cells increased in number towards the caudad end of the area. The general appearance of the glands and the interglandular substance suggested a gradual transition from the mucous membrane of small to that of large intestine.

(*e*) The central area, to each side of the middle line (fig. 1), showed the same appearance as (*d*).

(*f*) The small diverticulum at the surface opening of the large intestine

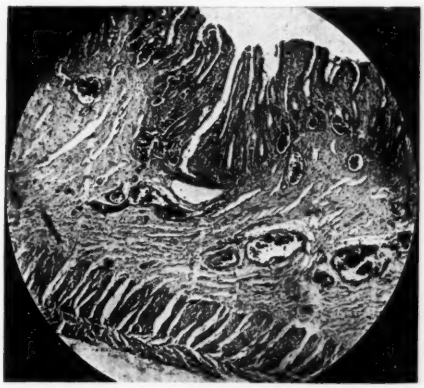

FIG. 4.—Sagittal section through area in median plane between the orifices of the small and large intestine, showing the typical muscular coat and typical villi of the small intestine.

(C, fig. 2) was lined by mucous membrane which, in its caudad part, presented all the characteristics of the mucous coat of the large intestine. In its cephalad part this area was identical with the caudad part of (*d*). No lymphoid tissue was found in the submucosa.

(*g*) Large intestine. The surface was covered by columnar epithelium, which dipped in to line simple tubular glands. The cells were practically all mucus-secreting. The general appearance was identical with that found in the large intestine of a normal fœtus.

(*h*) The lateral area was much denuded of its surface layer, which, however, was intact in places. It consisted of stratified epithelium of the type usually found in the urinary bladder. The submucous tissue contained many plain muscle and white connective-tissue fibres. All the blood-vessels

were greatly engorged, and extravasated blood was found amongst the submucous tissue.

(*i*) The central area, caudad to the opening of the large intestine (fig. 5), was covered by stratified epithelium similar to that found in (*h*), but in a state of better preservation. Embedded in the submucous tissue there was a tube, the walls of which were lined by squamous epithelium. It is possible that this represented the terminal part of the left vagina, but, as the area was not cut serially, it was not determined whether it opened on the surface or with what it was connected above.

(*k*) Sections of the clitoris, uteri, and vaginæ were examined, and the identity of these structures was confirmed.

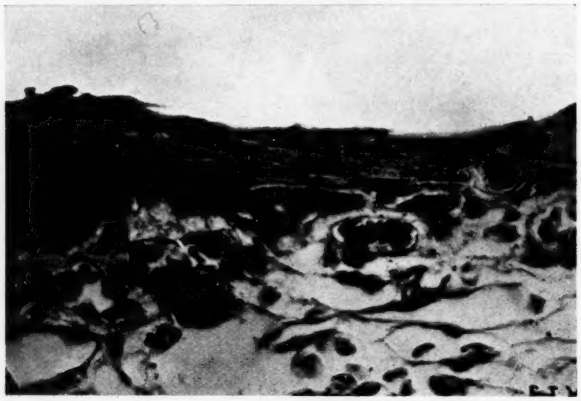

FIG. 5.—Section through area caudad to orifice of large intestine, showing surface covered by transitional stratified epithelium of the type found in the bladder wall.

*Historical.*—The recorded cases of extroversion of the bladder and its kindred anomalies are extremely numerous. In 1865, Förster (5) collected a number of cases of epispadias, of pure extroversion of the bladder, and of cases similar to the one described in this paper. He referred to the last group as examples of "Kloakbildung," but the term is used not in its morphological sense, but to express the fact that the urogenital ducts and alimentary canal open on the same surface. He believed the condition to be due to an arrest of development at an early period. "In diesen Fällen ist also der Enddarm, nachdem die Allantois aus ihm hervorgewachsen, allmählig wieder geschwunden und der Mitteldarm ist offen geblieben, verharrt also bleibend auf der Entwickelungsstufe der dritten oder vierten Woche des embryonalen Lebens."

Wood (6), in 1865, described eight cases of pure extroversion of the bladder, and suggested the following explanation: "An important observation has been made in these cases, that, at the time of birth, the hypogastric surface of the fœtus, from the umbilicus to the genital organs, is usually found to be adherent to the placenta or its membranes, the adhesions becoming separated by the process of parturition at the parts in which the cicatrised appearance is afterwards found. Such an adhesion explains very fully how the anterior or superficial portions only of the structures implicated are afterwards found to be deficient." With regard to the complicated variety, his view is that "these are evidently cases in which the arrest of development has taken place at an earlier period, while the fœtus still presents a cloacal formation." Later observations have failed to confirm the presence of adhesions between the extroverted area and the placenta, and, indeed, it is difficult to imagine how such adhesions could be so limited as to produce exactly similar results in each case.

In 1877, Champneys (7) reviewed the literature, and gave a brief account of the theories as to causation which had been brought forward up to that time. He groups them under the following headings: "A, Mechanical; B, Pathological; C, Developmental, or combinations of them." He criticises the views of Breschet (8), Duncan (9), and Mörgelin (10), who all held to the "Berstungstheorie" or mechanical explanation; Velpeau (11) and Phillips (12), who believed the condition to be due to destruction of the bladder and abdominal walls by ulceration; Meckel (13), Wood (6), and others, who all supported the "Hemmungsbildungtheorie." Champneys sums up as follows: "There can be little doubt that the theory which attributes the deformity to arrest of development is the correct one, because the other theories do not bear inspection, some of them being even unimaginable; because of the frequency of accompanying proofs of arrested development; and, lastly, because of the known development of the allantois." With regard to the last point, Champneys believed that the allantois arose as a bilateral structure, and that the two parts ultimately fused to form the bladder and the urogenital sinus. He supposed that failure of the ventral walls of the two allantoic diverticula to unite produced extroversion of the bladder, and that, when both dorsal and ventral walls failed to unite, the condition of extroversion of the cloaca was brought about. It is now known that the allantois does not arise as a paired structure in the human embryo, and, in any case, the explanation fails to account satisfactorily for the accompanying fissure of the abdominal wall.

In 1880, Ahlfeld (14) collected a number of cases and expressed the view that the intestinal openings on the extroverted area represent a patent vitello-intestinal duct. "Der Umstand, dass in einigen Fällen (Meckel,

*Reil's Archiv.*, Bd. 9, S. 449, und Rose, *Monatsschrift für Gebürtskunde*, Bd. 26, S. 244) bestimmt angegeben wird, ein vas omphalo-mesaraicum sei vom widernatürlichen After in der Blasenwand zum Mesenterium gelaufen, beweist dass an dieser Stelle der Ductus eingemündet hat und dort abgerissen sein muss. . . . Ich halte das Zwischenstück von Darmschleimhaut nur für eine probabirte Partie bei ziemlich weiter Dottergangspalte."

In 1881, Doran (15) recorded a similar case of extroversion, and concluded that "failure of union of the visceral plates in the abdominal region, arrested development of the intra-abdominal part of the allantois, and persistence of a primitive condition of the alimentary tube in the region of the omphalo-mesenteric duct will account for the protrusion of the viscera, the condition of the bladder, and the opening of the intestine by an aperture far above its blind extremity and above the imperfect vesical elements." Doran assumed that the intestinal orifice was the patent omphalo-mesenteric duct, but the vague nature of his explanation gives no reason for its presence below the umbilicus. This case presents certain peculiarities which are not found in other examples of the condition, including what Keith (1) assumes to be persistence of the post-anal gut. Unfortunately no account is given of the histology of the region, and, without that, the identification of a tube, opening in the neighbourhood of the groin, as post-anal gut cannot be taken as certain.

Shattock (16), in 1887, writing on pure extroversion of the bladder, suggested that "the primitive cloacal invagination of the surface which normally lays open the lower end of the rectum and the lower end of the urogenital sinus, does in these cases, by an undue extension forwards and upwards, lay open the anterior wall of the urogenital sinus and the anterior wall of the bladder." In support of his view he evidenced the fact that epispadias invariably accompanies pure extroversion of the bladder.

In 1894, the same author (3) recorded the microscopic appearances of the mucous membrane in another similar case. He states that the investing epithelium shows a regular series of deep ingrowths; "it is not a papillary production or one due to outgrowths, for the free surface is in the intervals smooth for what are, microscopically, considerable distances." The general appearance is like "an adenoma arising in the intestinal mucosa, except that no antecedent gland tissue is concerned in its production." In considering these statements the reader must bear in mind that the preparation was obtained from an adult, aged 38, who had worn a urinal for 34 years, and who was the subject of suppurative inflammation of the right kidney.

In 1895, Bryce (17) published a case of complicated extroversion in a fœtus, which was the subject of retroflexion of the trunk, ectopia viscerum,

and spina bifida. He criticised Ahlfeld's view that the intestinal openings, represent a patent vitello-intestinal duct, and, in the light of His' description of the development of the bladder, came to the conclusion that "cases of anus vesicalis must, therefore, be explained by imperfection in the formation of the septum," which normally divides the cloaca into a ventral, urinary, and a dorsal, alimentary, segment. In this case the ileum and a blind dilated sac—which seems to represent the large intestine—opened by a common orifice on the surface of the extroverted bladder. Bryce suggests that this sac "represents not the whole intestine behind the yolk stalk, but the much-dilated 'bursa pelvis'" (the name given by His to the cloaca interna). He believes that the primary cause of the whole series of abnormalities present in this case lies in the retroflexion of the trunk, and suggests that the persistence of a very short allantoic stalk has interfered with the growth in the pelvic region and resulted in the abnormalities found. No reason is given for the rupture of the bladder or cloaca, and though the shortness or absence of the umbilical cord might account for this particular case, it cannot account for the similar conditions found in cases like the one recorded in the present paper, where the umbilical cord is normal.

It is interesting to compare Bryce's case with the one recorded by Emrys-Roberts and Paterson (18) in 1906. The condition of the fœtus was very similar, with two important exceptions. No red mucous-membrane covered area was exposed on the surface; the ileum was normal and became continuous, with a short dilated tube which opened at its lower end into an internal cloaca. This case is quoted by Keith (1) as an example of "Extroversion of the Bladder with a Meckel's Diverticulum opening on the Surface," but the reason for identifying what is almost certainly an orifice in the large intestine as the opening of a patent Meckel's diverticulum is by no means clear. Emrys-Roberts and Paterson follow Fleischman's (19) description of the development of the bladder. In consequence, they conclude that the allantois was absent in their case and that "most if not the whole series of malformations appear to have been primarily caused by the failure in development of the hinder portion of the alimentary canal." No indication is given of the nature or of the cause of the arrest of development, but it is suggested that "the period at which arrest of development has occurred appears to be after the formation of the cloaca, but before the separation of rectal and genito-urinary passages."

In 1896, Sequeira (20) recorded a case in which a funnel-shaped orifice in the middle line communicated with the ileum and the large intestine. This he regards as a patent vitello-intestinal duct. With reference to the

causation, he supports the views of Shattock, which have been mentioned above. "If, as in the present case, the vitelline duct opens at the umbilicus, it would, of necessity, be involved in this forward extension of the proctodœum."

In 1900, von Steinbüchel (21) recorded a case of extroversion in which two small openings, placed one on each side of the middle line, communicated with what he believed to be a Meckel's diverticulum. The large intestine was very rudimentary, and, according to the writer, was represented only by the cæcum. He believes that pure extroversion of the bladder is the first step, and that, at the same time, the large intestine fails to develop. Thereafter "der Ductus omphalo-mesaraicus . . . drängt sich zwischen die beiden noch getrennten anlage der Harnblase . . . und verlöthet sich mit jeder der beiden Blasenanlagen. Durch den Druck des Meconiums, der im Ductus immer bedeutender wird, da ja der Dickdarm nicht ausgebildet ist und sich an das unterste Ilium nur ein kleiner, blind endigender Darmtheil (Cæcum) anschliesst, erfolgt schliesslich in die vielleicht mittlerweile schon vereinigten Blasenhälften der Durchbruck, so dass wir symmetrisch von der Mittellinie zwei Oeffnungen, die in das Darmrohr führen sehen." The chain of events is so complicated that it is improbable that this is the correct explanation. It is curious to find that, after rejecting the Berstungstheorie with regard to extroversion of the bladder, von Steinbüchel resorts to that theory in order to explain the presence of a communication with the alimentary canal.

In 1901, Berry Hart (22) discussed the question of pure extroversion of the bladder, and came to the conclusion that its causation might be ascribed to an abnormally extensive rupture of the cloacal membrane. With regard to those cases in which the alimentary canal opens on the surface of an extroverted bladder, he was hardly prepared to accept von Steinbüchel's explanation, but he offered no other solution.

In 1904, Enderlen (4) examined the mucous membrane of the extroverted bladder in two new-born children. He found "das Uebergangsepithel der Blase mehr oder weniger gut erhalten." In adults, who were the subject of this malformation, his results were different, "Plattenepithel in verschiedener Form wechselt mit verschieden gestaltetem und funktionierendem Zylinderepithel ab." This he regarded as a metaplasia, although Keith (1) puts a somewhat different interpretation on the facts.

In 1908, Keith (1) classified the malformations of the hind-end of the embryo. He included all cases in which intestinal openings are present on the surface of an extroverted bladder in one group, to which he referred as "Ectopia Vesicæ with a Meckel's Diverticulum opening on the exposed vesical surface." In giving a brief account of the characteristic features

of the condition, he says that the intestinal orifice may vary in position. "It may be situated almost in the perineum, near the posterior angle of the exposed mucous area." How the orifice of a Meckel's diverticulum comes to open at a point so far distant from the umbilicus is not explained. Further, he states that "the depression into which the ileum and cæcum open . . . is usually lined by a villous mucous membrane," but he does not mention the grounds on which this observation is based. He is of opinion that the condition is due to an arrest of development occurring at about the period shown in the Graf Spee embryo "Gle," and suggests that the allantois fails to become differentiated. As a result "the hind-end of the embryo, with the primitive streak, rests directly on the yolk-sac, instead of being separated from it by the allantois and the cloaca, as in the Graf Spee embryo. The primitive streak thus comes to rest directly over that part of the yolk-sac where the unseparated rudiment of the cloaca is situated. If an opening were to occur in the primitive streak, the yolk-sac and endodermal cloaca would open on the hypogastric region of the embryo, and give rise to the condition seen where ectopia vesicæ is combined with a fistula opening into the intestine." Later he says, "It is plain . . . that ectopia vesicæ is due to a non-fusion of the lips of the hypogastric stretch of the primitive streak." Keith believes that the active agent is chorionic inflammation during the third week of embryonic life, "when the chorionic circulation is being established, and that is just when the lips of the primitive streak are in a state of fusion, a fusion which is to secure the anterior closure of the bladder and lower belly wall." In referring to Enderlen's work he omitted to mention that in the only cases of new-born children which Enderlen examined the mucous membrane was typical bladder epithelium. Keith cut sections of the junctional area between the "part supposed to be yolk-sac or its stalk" and the bladder. The former he found "lined by a double layer of columnar epithelium, while that supposed to be vesical mucous membrane was covered by a stratified epithelium similar to that which covers the lips of the mouth." He also cut sections from the mucous membrane in a case of pure extroversion of the bladder, and found that "unfortunately all the epithelium had been lost, but it showed villous processes with depressions between their bases, recalling the structure of the small intestine, and quite unlike the mucous membrane of the normal fœtal bladder."

In 1910, Wood Jones (2) advanced a theory which is diametrically opposed to the views of Keith. He believes that "abnormal distension of the allantois and urinary tract" is the causative factor, and, consequently may be taken as a supporter of the "Berstungstheorie." Two stages are necessary for the production of the deformity. In the first instance the

allantois becomes greatly distended and "encroaches on" the yolk-sac. It is not quite clear what the author wishes to be understood by the term "encroach." In his hypothetical figure he shows that after the "encroachment" the yolk-sac and allantois are thrown into a common sac, which receives the openings of the caudal end of the fore-gut and the cephalic end of the hind-gut. In the second instance this common sac ruptures on to the surface. Wood Jones calls attention to the position of the umbilical arteries relative to the extroverted area, and suggests that a study of this point should decide whether it is the yolk-sac or the allantois which ruptures. "The information to be gathered concerning the actual disposition of the membranes and vessels at the time of birth seems to be very slight, but such accounts as are available agree that a sort of skirt of membranes is attached—on the one hand around the margins of the exposed red area, and on the other to the placenta." The author concludes with the statement that "the typical human body-stalk placentation is lost, and a highly developed allantoic placentation has taken its place." No account is given of the histology of any of the parts described.

As Champneys has pointed out, the explanation of this condition must be given in the light of the currently accepted views on the development of the hind-end of the embryo. It is now generally believed that the allantois takes little or no part in the formation of the bladder, which is derived entirely from the endodermal cloaca. This view was first put forward by Keibel (24), and has recently been fully substantiated by Pohlmann (23). Both these authorities agree that the endodermal cloaca does not normally open on the surface. According to Pohlmann, the primitive streak consists of all three germ layers, and that, after the formation of the tail-fold, the mesoderm disappears, leaving the ectoderm in apposition with the endoderm as the cloacal membrane. The subdivision of the cloaca into ventral, urinary, and dorsal, intestinals egments involves the subdivision of the cloacal membrane into urogenital and anal parts, which break down, independently of each other, at a later period. Normally, the subdivision of the cloaca is effected by the tailward growth of a frontal mesodermal septum.

It may be as well to point out at this stage that the term cloaca is used to indicate that part of the primitive gut which lies caudal to the point of origin of the allantois after the formation of the tail-fold, and that, in the early stages, the terms cloaca and hind-gut are synonymous. As growth proceeds, the extent of the cloaca relative to the extent of the gut rapidly becomes smaller, so that the segment of gut derived from the subdivision of the cloaca is very much shorter than would have been the case if the subdivision occurred at an earlier stage.

Rupture of the urogenital and anal segments of the cloacal membrane is a perfectly normal occurrence at a certain period of development, and this fact, as pointed out by Berry Hart, at once suggests a clue to the causation of cases of epispadias and extroversion of the bladder. In hypospadias the urogenital membrane breaks down at the normal time and to a normal extent. If, however, the membrane ruptures cephalad to the genital tubercle instead of caudal to it, the condition of epispadias is produced; and if the rupture is excessive—the membrane is probably more extensive in these cases—pure extroversion of the bladder plus epispadias is the result. Both the conditions of epispadias and pure extroversion can therefore be accounted for on the ground of rupture of the urogenital membrane at an abnormal site but at the normal time.

It may be as well to indicate the reasons for rejecting the theories which have hitherto been advanced before attempting to offer a somewhat different explanation. For a criticism of the earlier theories the reader is referred to a paper by Champneys (7), whose own theory is rendered untenable by our present knowledge of the development of the allantois. Ahlfeld (14) and Bryce (17) both believe that abnormal shortness of the umbilical cord is the active agent, but the former holds that it is the vitello-intestinal duct which opens on the surface, whereas the latter inclines to the view that it is the cloaca only. This view, however, can only apply to those cases in which the umbilical cord is absent or unusually short, and cannot be regarded as explanatory of all the recorded cases.

Emrys-Roberts and Paterson (18) do not put forward any theory with regard to the causation of the condition, but they agree with Bryce in believing that the arrest of development occurs before the separation of the bladder and gut segments of the cloaca.

Sequeira's (20) explanation is very similar to that brought forward by Keith (1). He applies Shattock's explanation of pure extroversion of the bladder to the more complicated condition, but he omits to explain how the rupture of the cloacal membrane can pass forwards to involve the vitello-intestinal duct in the presence of the allantois. Further, it is almost certain that he believes the condition to arise after the bladder has been completely shut off from the gut, and the extension, at that period, of a rupture of the bladder to the yolk-sac or its duct would necessarily involve the opening up of the cœlom.

Von Steinbüchel (21), as already pointed out, postulates a number of anomalies, all occurring in the same embryo, together with a pathological process. The statement that the hind-gut fails to develop after its separation from the bladder is untenable, since by the time that the separation has occurred there is a relatively large segment of gut caudad to the vitello-

intestinal duct. Von Steinbüchel's view appears to be much too complex to be capable of explaining every case of this anomaly.

Keith (1) adopts a somewhat different explanation. In the first place, he postulates the absence or non-differentiation of the allantois, a hypothesis which is rendered necessary by his interpretation of the intestinal orifices as the surface opening of the vitello-intestinal duct. He suggests that during the third week of embryonic life, "when the lips of the primitive streak are in a state of fusion," chorionic inflammation so alters the condition of growth that "non-fusion" follows. The statement that the fusion of the lips of the primitive streak "is to secure the anterior closure of the bladder and lower belly wall" is rather misleading, as it suggests that the ventral wall of the bladder is at first absent. Pohlmann (23) has shown that the cloacal membrane is formed by the disappearance of the mesoderm from the region of the primitive streak, *i.e.* that normally there is a decrease in substance in this area and not an increase, as the word "fusion" would lead one to suppose. It is not clear in what sense Keith employs the word "cloaca," but from the quotations given on p. 99 it would appear that the primitive streak takes no part in the formation of its walls. These views are at variance with those of Keibel, Pohlmann, and other authorities, and certainly the suggestion that the bladder is closed ventrally by the fusion of the lips of the primitive streak receives no support from the recent work on this subject. Although making the statement that "the vitelline orifice . . . may be situated almost in the perineum," Keith offers no reason for this very unexpected position of a structure which should open at the umbilicus, nor does he make any reference to the histology of the area which intervenes between the umbilical cord and the orifice of the small intestine. As will be shown later, the nature of this area is of the greatest importance in determining the nature of the anomaly.

Wood Jones (2) re-advocates the "Berstungstheorie," and believes that the whole condition is due to overdistention and rupture of the allantois. This takes place before the closure of the neurenteric canal, and so accounts for the associated spina bifida. He makes no attempt to prove that at this early stage the mesonephros is capable of active excretion, nor does he explain why the allantois ruptures into the yolk-sac instead of to the exterior. Further, rupture of the allantois would necessarily involve a tearing of the umbilical cord, and, as has been shown, that structure was perfectly normal in the case recorded in the present paper. I have been unable to trace the authority for the statement that "such accounts as are available agree that a sort of skirt of membranes is attached, on the one hand, around the margins of the exposed red area, and, on the other, to the placenta," but certainly no such condition was present in the case here

recorded. There is another objection to be put forward from the purely mechanical standpoint. If the internal pressure is sufficiently great to prevent the closure of the neurenteric canal, how is it possible for the normal separation of bladder and gut to go on undisturbed, as shown by Wood Jones in his figs. 10 and 11 ?

Extroversion of the bladder, complicated by the presence of openings into the alimentary canal, can be most easily and most satisfactorily explained by rupture of the cloacal membrane occurring at an abnormally early period. If such a rupture occurred during or immediately after the formation of the tail-fold, it would expose the dorsal and lateral walls of the cloaca or hind-gut. As the lateral walls of the cloaca are concerned in the formation of the bladder, it is in keeping with this explanation to find that the lateral parts of the extroverted area in the present case are histologically identical with bladder wall. The central part of the extroverted area should represent those parts of the alimentary canal which are normally formed from the hind-gut or cloaca. As this area has been shown to represent the terminal part of the ileum and the whole of the large intestine, it would appear at first sight as if the above hypothesis were untenable. It is therefore necessary, before proceeding further, to endeavour to determine how large a part the hind-gut takes in the formation of the adult alimentary canal. In an embryo of 13–14 primitive segments (Embryo Pfannenstiel III., fig. 526, *Keibel and Mall's Manual of Human Embryology*) the origin of the allantois lies opposite the 14th primitive segment, practically at the junction of mid- and hind-gut. In an embryo of 23 primitive segments (Embryo R. Meyer 300, fig. 531a, *Keibel and Mall's Manual of Human Embryology*) the origin of the allantois lies opposite the 23rd primitive segment, while the caudal end of the mid-gut lies opposite the 12th segment. Opposite segments 13–22 there is a part of the alimentary canal which connects the mid-gut with the cloaca, and, from the figures given by Lewis (25), it seems almost certain that the cæcum appears on this part at a slightly later stage. Careful consideration of the available reconstruction models and figures leads to the opinion that, in the growth of the alimentary canal, the region in connexion with the yolk-sac remains practically a fixed point, and that the areas on each side are areas of active growth—*i.e.* the fore-gut and the hind-gut are responsible for practically the whole of the adult alimentary canal.

Abnormally early and excessive rupture of the cloacal membrane exposes the dorsal wall of the hind-gut, which is destined to form the terminal part of the ileum (caudal to the usual site of a Meckel's diverticulum) and the whole of the large intestine. The destruction of

the ventral wall and the exposure of the dorsal wall apparently constitute a condition which greatly restricts the growth of the hind-gut, and the tailward-growing mesodermal septum fails, so that the subdivision of the cloaca is not carried out.

The presence in this and in other cases of a tubular part of the large intestine is a difficulty which requires to be considered. It is possible that it represents persistence of the post-anal gut. In Doran's (15) specimen, however, there was, in addition to a tubular part of large intestine, a small canal, lined by mucous membrane, which opened on the extroverted area and also in the groin. If Keith (1) is correct in his identification of this structure as the persistent post-anal gut, a different explanation must be sought to account for the formation of the tubular part of the large intestine.

Pohlmann (23) believes that, normally, the tailward-growing mesodermal septum is the active agent in shutting off the bladder from the gut, and he holds that the lateral folds of Rathke are more apparent than real. The subdivision is completed by the fusion of this septum with the mesodermal bar, which invades the cloacal membrane and separates it into urogenital and anal segments. It should be remembered that this frontal septum is not horizontal, but crescentic in outline, and that the failure of its central part does not necessarily involve its lateral parts. In order to account for the formation of a tubular part of the large intestine in these cases of extroversion, it is necessary to assume that the central part of the frontal septum fails to develop, and that, under these abnormal conditions, its lateral parts grow inwards and fuse with one another and the mesodermal bar in the perineum. In this way the caudad part of the bladder is separated from the caudad part of the gut, while the two remain undivided in their cephalad portions. At present this explanation cannot be definitely proved, but the conditions found suggest that it is very probably correct. It should be pointed out, however, that this same difficulty is present in the explanations offered by Keith and all the other writers save Wood Jones—who has his own views with regard to the formation of the terminal portion of the alimentary canal,—and that none of these authorities has made any attempt to overcome it.

The histological nature of the area which lies cephalad to the opening of the small intestine and caudad to the umbilicus gives strong support to the explanation offered in this paper. If the opening into the alimentary canal is really the vitello-intestinal duct, as Sequeira (20), Doran (15), Keith (1), and others hold, then the presence of skin on the surface of this area requires to be explained. The vitello-intestinal duct, when patent, invariably opens at the umbilicus, and it is impossible for it to open

where, except in the event of pathological lesions. The assumption that the proximal part of the umbilical cord has been taken into the anterior abdominal wall during the process of growth would provide a way out of the difficulty, but no proof has yet been brought forward in its support. The histological findings, however, are in perfect accordance with the present explanation, for, the cloacal membrane having ruptured up to the point of the allantois, the umbilical cord is left intact, together with a small area on the anterior abdominal wall caudad to the umbilicus. If, at a later date, some observer is able to demonstrate the presence of bladder mucous membrane, intervening between the orifice of the small intestine and the umbilical cord, then the case for abnormally early and excessive rupture of the cloacal membrane will be established beyond doubt.

## Summary.

(1) Epispadias is due to rupture of the urogenital part of the cloacal membrane at a site cephalad instead of caudad to the genital tubercle.

(2) Pure extroversion of the bladder, together with epispadias, is due to an excessive degree of the same rupture.

(3) Extroversion of the bladder, complicated by intestinal openings on the extroverted area, is due to rupture of the cloacal membrane. This rupture may occur at any time between the first appearance of the membrane and the completion of the subdivision of the cloaca. The period at which it takes place will determine the variety of the anomaly; thus it is suggested that the rupture occurred very early in the case recorded in this paper, and at a later period in the case described by Emrys-Roberts and Paterson (18).

(4) Spina bifida and paired diverticula at or near the surface orifice of the large intestine are not constant features of cases of extroversion of the bladder, complicated by intestinal openings on the extroverted area.

(5) The primitive hind-gut gives origin to a much larger part of the alimentary canal than is generally supposed, whereas the mid-gut forms very much less than is usually ascribed to it.

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